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CHARTS FOR APPROXIMATE THERMODYNAMIC PROPERTIES OF NITROGEN-OYXGEN MIXTURES

FOWLER and BROWN

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CHARTS FOR APPROXIMATE THERMODYNAMIC PROPERTIES OF NITROGEN-OYXGEN MIXTURES

BY BRUCE FOWLER and RONALD D. BROWN

Langley Research Center

Scientific and Technical Information Division 1965
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FOREWORD

The purpose of this paper is to present data, determined by one consistent approach, on the thermodynamic properties of nitrogen and three nitrogen-oxygen compositions and the dimensionless speed-of-sound parameter for each. These properties have been calculated over a temperature range from 200° to 15,000° K for a pressure range from 10^{-4} to 10^{2} atmospheres. The data are presented in a combination of Mollier charts and tables so that aerodynamic expansions can be performed. The results, which agree closely with more rigorous calculations, are considered suitable for engineering purposes.

CONTENTS

SUMMARY

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Charts have been prepared which show the equilibrium thermodynamic properties of four nitrogen-oxygen mixtures, one of which approximates air (80 percent N_2 and 20 percent O_2, by volume). The temperature range was from 200° to 15,000° K and the pressure range, from 10^{-4} to 10^2 atmospheres. The thermodynamic properties have been computed in closed form, starting from the approximate partition functions.

Author

INTRODUCTION

One of the factors affecting the performance of the charring ablators which are used as thermal protective structures on high-speed reentry vehicles is oxidation. It has been shown in references 1 and 2 that oxidation varies directly as the oxygen concentration and inversely as the enthalpy of the environment.

In the actual reentry, the enthalpy is frequently higher than can be attained in the usual arc-heated wind-tunnel ground facility. In order to simulate the same oxidation and its effects in such a facility, the oxygen concentration must be reduced in direct proportion to enthalpy. These changes in the ratio of oxygen to nitrogen require thermodynamic charts to evaluate the desired aerodynamic characteristics.

In the present paper, Mollier charts of the equilibrium thermodynamic properties for four nitrogen-oxygen mixtures are presented. These charts have been prepared by using a generalized version of the procedure utilized by Hansen (ref. 3). Only the essential equations required for complete understanding and computation are presented in the text. The more detailed presentation and development of the equations and computation procedure can be found in reference 3.

Pressure and temperature are plotted as a function of enthalpy and dimensionless entropy. The temperature ranges from 200° K to 6,000° K at 200° increments and from 6,000° K to 15,000° K at 500° increments. Pressure ranges from 10^{-4} to 10^2 atmospheres with five equal divisions between orders of magnitude.

SYMBOLS

An enthalpy scale is presented on all charts both in the U.S Customary Units and in the International System of Units, SI. Factors relating the two systems are given in reference 4.

a	speed of sound
a_i, b_i	stoichiometric coefficients for species A_i and B_i, respectively
A_i, B_i	chemical species
c_p	heat capacity per mol at constant pressure
c_v	heat capacity per mol at constant density
D	dissociation energy per molecule
E	energy per mol
E_o	energy per mol at zero absolute temperature
g_j	degeneracy of the jth state
g_n	degeneracy of the nth electronic state
h	Planck's constant
H	enthalpy per mol
I	molecular moment of inertia, also ionization energy per molecule
k	Boltzmann constant
K_p	chemical equilibrium constant based on partial pressure
$K_{p,1}$	equilibrium constant for oxygen dissociation reaction
$K_{p,2}$	equilibrium constant for nitrogen dissociation reaction
$K_{p,3}$	equilibrium constant for atom ionization reactions
m	mass of gas particle
M	molecular weight
M_o	molecular weight of undissociated mixture

n concentration in moles per unit volume

p pressure

p_o reference pressure, 1 atmosphere

Q partition function

Q_p pQ where p is unit pressure

R universal gas constant

S entropy per mol

S_o entropy per mol at 1 atmosphere pressure

T absolute temperature

x mol fraction

$Z = M_o/M$

α molecular symmetry number

γ ratio of specific heats, c_p/c_v

ϵ_1 fraction of initial molecules of oxygen which are dissociated

ϵ_2 fraction of initial molecules of nitrogen which are dissociated

ϵ_3 fraction of atoms which are ionized

ϵ_j energy of the jth state

ϵ_n energy of the nth electronic state

ν vibrational frequency

ρ density

φ_{N_2} volume percent of N_2 molecules in initial undissociated composition

φ_{O_2} volume percent of O_2 molecules in initial undissociated composition

Subscripts:

i index referring to molecule type

int internal

t,r,v,e indices referring to the contribution of translational, rotational, vibrational, and electronic energy modes, respectively

FUNDAMENTAL RELATIONS

The thermodynamic properties of four mixtures of nitrogen and oxygen were calculated on a high-speed digital computer by using the method and equations from Hansen (ref. 3). The program was generalized so that the initial concentration of nitrogen and oxygen and the weight of the undissociated molecules of each mixture were inputs. Therefore, the program allows complete flexibility for any mixture of nitrogen and oxygen.

The principal assumptions made for the thermodynamic calculations were the same as Hansen (ref. 3) and are as follows: each gas species obeys the ideal equation of state; individual diatomic molecules are rigid rotor-harmomic oscillators; the reactions are nitrogen and oxygen dissociation and atomic ionization; and formation of NO (nitric oxide) is neglected.

Partition Function

All the thermodynamic properties of a gas may be calculated from its partition function. The partition function is defined as

$$Q = \sum_j g_j e^{-\frac{\epsilon_j}{kT}} \tag{1}$$

where ϵ_j is the energy of the jth state and g_j is the degeneracy of the jth state. The total partition function may be expressed as a product

$$Q = Q_t Q_r Q_v Q_e \tag{2}$$

The factors on the right-hand side of equation (2) are the partition functions associated with the translational, rotational, vibrational, and electronic energy modes of the gas particle. From the method of statistical mechanics the partition functions can be expressed as follows:

$$Q_t = \left(\frac{2\pi mkT}{h^2}\right)^{3/2} \frac{RT}{p} \tag{3}$$

$$Q_r = \frac{8\pi^2 IkT}{\sigma h^2} \tag{4}$$

$$Q_v = \left(1 - e^{-\frac{h\nu}{kT}}\right)^{-1} \tag{5}$$

$$Q_e = \sum_{n=0}^{\infty} g_n e^{-\frac{\epsilon_n}{kT}} \tag{6}$$

Values of all numerical constants and the complete partition-function expression for each species are given in table I and appendix A, respectively.

Equilibrium Constant

The reactions considered can be generalized by the following expression:

$$\sum_i a_i A_i \rightleftarrows \sum_i b_i B_i \tag{7}$$

where A_i and B_i are the reactants and products, respectively, and a_i and b_i are the corresponding stoichiometric coefficients.

The pressure equilibrium constant can be defined in terms of the partial pressures:

$$K_p = \frac{\Pi p^{b_i}(B_i)}{\Pi p^{a_i}(A_i)} \tag{8}$$

and is related to the partition functions by (see ch. VIII of ref. 5)

$$\ln K_p = -\frac{\Delta E_o}{RT} + \sum b_i \ln Q_p(B_i) - \sum a_i \ln Q_p(A_i) \tag{9}$$

where $Q_p = pQ$ for p = unit value and

$$\Delta E_o = \sum b_i E_o(B_i) - \sum a_i E_o(A_i) \tag{10}$$

is the zero-point energy difference between the products and the reactants, both referring to the standard states.

Mole Fraction

The equation of state will be defined as

$$\frac{p}{\rho} = \frac{ZRT}{M_o} \tag{11}$$

where Z is the molecular weight ratio M_o/M. If ϵ_1 is the volume fraction of initial molecules that are dissociated into oxygen atoms, ϵ_2 is the volume fraction of initial molecules that are dissociated into nitrogen atoms, and ϵ_3 is the volume fraction of original atoms that are ionized after dissociation is completed, then the molecular-weight ratio is

$$Z = 1 + \epsilon_1 + \epsilon_2 + 2\epsilon_3 \tag{12}$$

The reactions are now assumed to be independent and to follow in sequence. The O_2 dissociation is assumed to be complete prior to N_2 dissociation and all dissociation to be complete prior to any ionization. The initial percentages of nitrogen and oxygen are taken as φ_{N_2} and φ_{O_2}, respectively. Only three major components exist at relatively low temperatures: molecular nitrogen, molecular oxygen, and atomic oxygen. The equilibrium constant for the oxygen dissociation reaction can be equated to the oxygen partial pressures expressed in terms of φ_{O_2} and ϵ_1. The first dissociation fraction is then given by

$$\epsilon_1 = \frac{-\varphi_{N_2} + \sqrt{\left(\varphi_{N_2}\right)^2 + 4\varphi_{O_2}\left(1 + \frac{4p}{K_{p,1}}\right)}}{2\left(1 + \frac{4p}{K_{p,1}}\right)} \tag{13}$$

The limit where $\epsilon_1 = 0$ is the condition of no dissociation.

When the oxygen approaches complete dissociation $\epsilon_1 \to \varphi_{O_2}$ the nitrogen dissociation begins. The second dissociation fraction is similarly expressed by

$$\epsilon_2 = \frac{-\left(1.0 + \varphi_{O_2} - \varphi_{N_2}\right) + \sqrt{\left(1 + \varphi_{O_2} - \varphi_{N_2}\right)^2 + 4\varphi_{N_2}\left(1 + \varphi_{O_2}\right)\left(1 + \frac{4p}{K_{p,2}}\right)}}{2\left(1 + \frac{4p}{K_{p,2}}\right)} \tag{14}$$

As ϵ_2 approaches the limit φ_{N_2}, the dissociation of nitrogen is also complete and the ionization of the atoms begins. For the consideration of atomic ionization, it is assumed that the atoms are of a single homogeneous species, because the ionization potential of the oxygen and nitrogen atoms is approximately equal. The ionization fraction is thus

$$\epsilon_3 = \left(1 + \frac{p}{K_{p,3}}\right)^{-1/2} \tag{15}$$

where the equilibrium constant $K_{p,3}$ is taken as a population-weighted average of the constants for the nitrogen and oxygen ionization reactions; that is,

$$K_{p,3} = \varphi_{N_2} K_p(N \rightarrow N^+ + e^-) + \varphi_{O_2} K_p(O \rightarrow O^+ + e^-) \tag{16}$$

The component mol fractions of the gas mixture are

$$x_{O_2} = \frac{\varphi_{O_2} - \epsilon_1}{Z} \tag{17}$$

$$x_{N_2} = \frac{\varphi_{N_2} - \epsilon_2}{Z} \tag{18}$$

$$x_O = \frac{2\epsilon_1 - 2\varphi_{O_2}\epsilon_3}{Z} \tag{19}$$

$$x_N = \frac{2\epsilon_2 - 2\varphi_{N_2}\epsilon_3}{Z} \tag{20}$$

$$x_{N^+ + O^+} = x_{e^-} = \frac{2\epsilon_3}{Z} \tag{21}$$

Partial Derivatives

The derivatives of Zx_i will be required and it can be seen from equations (17) to (21) that the derivatives of Zx_i are proportional to $\partial\epsilon_1/\partial T$, $\partial\epsilon_2/\partial T$, and $\partial\epsilon_3/\partial T$. From equations (13), (14), and (16) the partial derivatives of ϵ_1, ϵ_2, and ϵ_3 at constant pressure are

$$\left(\frac{\partial\epsilon_1}{\partial T}\right)_p = \frac{\dfrac{d \ln K_{p,1}}{dT}}{\dfrac{2}{\epsilon_1} - \dfrac{1}{1 + \epsilon_1} + \dfrac{1}{\varphi_{O_2} - \epsilon_1}} \tag{22}$$

$$\left(\frac{\partial \epsilon_2}{\partial T}\right)_p = \frac{\dfrac{d \ln K_{p,2}}{dT}}{\dfrac{2}{\epsilon_2} - \dfrac{1}{\left(1 + \varphi_{O_2} + \epsilon_2\right)} + \dfrac{1}{\left(\varphi_{N_2} - \epsilon_2\right)}} \tag{23}$$

$$\left(\frac{\partial \epsilon_3}{\partial T}\right)_p = \frac{\dfrac{d \ln K_{p,3}}{dT}}{\dfrac{2}{\epsilon_3} - \dfrac{1}{1 + \epsilon_3} + \dfrac{1}{1 - \epsilon_3}} \tag{24}$$

The derivatives of Zx_i are

$$\left(\frac{\partial Zx_{O_2}}{\partial T}\right)_p = -\left(\frac{\partial \epsilon_1}{\partial T}\right)_p \tag{25}$$

$$\left(\frac{\partial Zx_{N_2}}{\partial T}\right)_p = -\left(\frac{\partial \epsilon_1}{\partial T}\right)_p \tag{26}$$

$$\left(\frac{\partial Zx_{O}}{\partial T}\right)_p = 2\left[\left(\frac{\partial \epsilon_1}{\partial T}\right)_p - \varphi_{O_2}\left(\frac{\partial \epsilon_3}{\partial T}\right)_p\right] \tag{27}$$

$$\left(\frac{\partial Zx_{N}}{\partial T}\right)_p = 2\left[\left(\frac{\partial \epsilon_2}{\partial T}\right)_p - \varphi_{N_2}\left(\frac{\partial \epsilon_3}{\partial T}\right)_p\right] \tag{28}$$

$$\left(\frac{\partial Zx_{e^-}}{\partial T}\right)_p = 2\left(\frac{\partial \epsilon_3}{\partial T}\right)_p \tag{29}$$

Similarly, the expressions for the partial derivatives of ϵ_1, ϵ_2, and ϵ_3 at constant density are

$$\left(\frac{\partial \epsilon_1}{\partial T}\right)_\rho = \frac{\dfrac{d \ln K_{p,1}}{dT} - \dfrac{1}{T}}{\dfrac{2}{\epsilon_1} + \dfrac{1}{\varphi_{O_2} - \epsilon_1}} \tag{30}$$

$$\left(\frac{\partial \epsilon_2}{\partial T}\right)_\rho = \frac{\dfrac{d \ln K_{p,2}}{dT} - \dfrac{1}{T}}{\dfrac{2}{\epsilon_2} + \dfrac{1}{\varphi_{N_2} - \epsilon_2}} \tag{31}$$

$$\left(\frac{\partial \epsilon_3}{\partial T}\right)_\rho = \frac{\dfrac{d \ln K_{p,3}}{dT} - \dfrac{1}{T}}{\dfrac{2}{\epsilon_3} + \dfrac{1}{1 - \epsilon_3}} \tag{32}$$

It follows that the expressions for the derivatives of Zx_i at constant density can be expressed the same as equations (25) to (29) except that the constant-pressure subscript is replaced by the constant-density subscript.

THERMODYNAMIC PROPERTIES

Pure Gas

According to statistical mechanics (for example, ch. VIII of ref. 5), the energy and enthalpy per mol of pure gas are given by

$$\frac{E - E_o}{RT} = T\left(\frac{\partial \ln Q}{\partial T}\right)_\rho \tag{33}$$

$$\frac{H - E_o}{RT} = T\left(\frac{\partial \ln Q}{\partial T}\right)_p \tag{34}$$

The energy and enthalpy per mol of gas due to translation and electronic excitation are given by

$$\left(\frac{E - E_o}{RT}\right)_{t+e} = \frac{3}{2} + \frac{\sum \dfrac{\epsilon_n}{kT} g_n e^{-\frac{\epsilon_n}{kT}}}{\sum g_n e^{-\frac{\epsilon_n}{kT}}} \tag{35}$$

$$\left(\frac{H - E_o}{RT}\right)_{t+e} = \left(\frac{E - E_o}{RT}\right)_{t+e} + 1 \tag{36}$$

For the molecular case the contributions of the rotational and vibrational energy must also be included. According to equations (4) and (5) the expression

$$\left(\frac{E}{RT}\right)_{r+\nu} = 1 + \frac{h\nu}{kT}\left(e^{\frac{h\nu}{kT}} - 1\right)^{-1} \tag{37}$$

should be added to equations (35) and (36).

The specific heat per mol at constant density of pure gas is

$$\left(\frac{c_v}{R}\right)_{t+e} = \frac{3}{2} + \frac{\sum \left(\frac{\epsilon_n}{kT}\right)^2 g_n e^{-\frac{\epsilon_n}{kT}}}{\sum g_n e^{-\frac{\epsilon_n}{kT}}} - \left(\frac{\sum \frac{\epsilon_n}{kT} g_n e^{-\frac{\epsilon_n}{kT}}}{\sum g_n e^{-\frac{\epsilon_n}{kT}}}\right)^2 \tag{38}$$

For the diatomic molecules

$$\left(\frac{c_{v,int}}{R}\right)_{r+v} = 1 + \left(\frac{h\nu}{2kT}\right)^2 \left(\sinh \frac{h\nu}{2kT}\right)^{-2} \tag{39}$$

should be added to equation (38). The specific heat per mol at constant pressure of a pure gas is

$$\left(\frac{c_p}{R}\right)_{t+e} = \left(\frac{c_v}{R}\right)_{t+e} + 1 \tag{40}$$

The entropy is

$$\frac{S}{R} = \ln Q + T\left(\frac{\partial \ln Q}{\partial T}\right)_p \tag{41}$$

Gas Mixture

Once the preceding relations have been determined the thermodynamic properties of the mixture follow readily.

The energy per mol of mixture, in the nondimensional form, is simply

$$\frac{ZE}{RT} = Z \sum_i \frac{E_i}{RT} \tag{42}$$

and the dimensionless enthalpy per initial mol is

$$\frac{ZH}{RT} = \frac{ZE}{RT} + Z \tag{43}$$

The entropy per mol is obtained from the entropies of the components by use of

$$\frac{ZS}{R} = Z\left(\sum_i x_i \frac{S_{o,i}}{R} - \sum_i x_i \ln x_i - \ln \frac{p}{p_o}\right) \tag{44}$$

The specific heat at constant volume is given by

$$\frac{Zc_v}{R} = \frac{1}{R}\left(\frac{\partial ZE}{\partial T}\right)_\rho = Z \sum_i x_i \frac{c_{v,i}}{R} + T \sum_i \left(\frac{E_i}{RT}\right)\left(\frac{\partial Zx_i}{\partial T}\right)_\rho \tag{45}$$

The corresponding specific heat for constant pressure is

$$\frac{Zc_p}{R} = \frac{1}{R}\left(\frac{\partial ZH}{\partial T}\right)_p = Z \sum_i x_i\left(\frac{c_{v,i}}{R} + 1\right) + T \sum_i \left(\frac{E_i}{RT} + 1\right)\left(\frac{\partial Zx_i}{\partial T}\right)_p \tag{46}$$

The ratio of specific heats γ is used to obtain the dimensionless speed-of-sound parameter which is given by

$$\frac{a^2\rho}{p} = \gamma \frac{1 + \left(\frac{T}{Z}\right)\left(\frac{\partial Z}{\partial T}\right)_\rho}{1 + \left(\frac{T}{Z}\right)\left(\frac{\partial Z}{\partial T}\right)_p} \tag{47}$$

DESCRIPTION OF CHARTS

The preceding equations have been used in a computer program to solve for the equilibrium thermodynamic properties of four nitrogen-oxygen mixtures. The temperature ranges from 200° to 15,000° K and the pressure ranges from 10^{-4} to 10^2 atmospheres. The data are presented in charts and tables. The charts appear just as they came from the computer-plotting system, which accounts for the minor waviness in some of the curves.

Included on the plots of enthalpy against entropy are lines of constant temperature and pressure. Molecular-weight ratio Z is plotted as a function of temperature with lines of constant pressure shown. Constant-density lines are not included. The density can be computed from the equation of state.

Figure 1 is a key for all the thermodynamic charts. Figure 1(a) shows the range of enthalpies and entropies to be found in the first 17 charts of each mixture and figure 1(b) shows the range of temperature and molecular-weight ratio Z to be found in the succeeding 4 charts (charts 18 to 21) for each composition. The curves used for reference on figure 1 are for the mixture of 80 percent N_2 and 20 percent O_2. The pressure divisions are noted only one time on each chart, but the divisions are consistent throughout all the data as five equal divisions between orders of magnitude.

Data for each composition are presented in thermodynamic charts and in reference tables of the ratio of specific heats γ and the dimensionless speed-of-sound parameter $a^2\rho/p$. The tables for each composition are placed immediately after the charts for the same composition. Data for 100 percent N_2 are given in figure 2 and table II; for 97 percent N_2 and 3 percent O_2, in figure 3 and table III; for 90 percent N_2 and 10 percent O_2, in figure 4 and table IV; and for 80 percent N_2 and 20 percent O_2, in figure 5 and table V. Figure 6 is a comparison of the degree of difference between the enthalpies of the two end-point compositions as a function of temperature at 1 atmosphere of pressure.

ACCURACY OF RESULTS

The data presented for N_2 in figure 2 and table II show close agreement with the data in reference 6. A maximum deviation in any parameter is less than 1.0 percent up to the temperature range where the double-ionization reaction occurs in reference 6. Since only single ionization was considered in the present paper, these data for higher temperatures are not comparable. A deviation of several percent exists at these higher temperatures.

Since essentially the same program used in reference 3 was used to obtain the data presented in figure 5, the results agree within about 0.5 percent. The specific heat ratios in table V also agree within about 0.5 percent with those of reference 3. The values of dimensionless speed-of-sound parameter, however, deviate from those in reference 3 by as much as 4 percent in the temperature range of nitrogen ionization. This difference is attributed to an omission of a factor of 2 in the ionization fraction of equation (A86) of reference 7 which is the basic program used in reference 3.

There are no data with which to compare figures 3 and 4 and tables III and IV but since the same program was checked at the end-point compositions it is assumed that the results are as valid as those for 100 percent N_2 and for 80 percent N_2 and 20 percent O_2. It should be noted that because of the unchanging limits of corresponding charts for each mixture, chart 4 of figure 2 has been omitted since no data for that mixture fell within the limits.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., December 21, 1964.

APPENDIX A

PRESSURE-INDEPENDENT PARTITION-FUNCTION EXPRESSIONS

The following equations for the pressure-independent partition functions, where temperature is in °K, were used in the calculations of the thermodynamic properties for nitrogen-oxygen mixtures:

$$\ln Q_p\left(N_2\right) = \frac{7}{2} \ln T - 0.42 - \ln\left(1 - e^{-\frac{3390}{T}}\right)$$

$$\ln Q_p\left(O_2\right) = \frac{7}{2} \ln T + 0.11 - \ln\left(1 - e^{-\frac{2270}{T}}\right) + \ln\left(3 + 2e^{-\frac{11390}{T}} + e^{-\frac{18990}{T}}\right)$$

$$\ln Q_p(O) = \frac{5}{2} \ln T + 0.50 + \ln\left(5 + 3e^{-\frac{228}{T}} + e^{-\frac{326}{T}} + 5e^{-\frac{22800}{T}} + e^{-\frac{48600}{T}}\right)$$

$$\ln Q_p(N) = \frac{5}{2} \ln T + 0.30 + \ln\left(4 + 10e^{-\frac{27700}{T}} + 6e^{-\frac{41500}{T}}\right)$$

$$\ln Q_p(O^+) = \frac{5}{2} \ln T + 0.50 + \ln\left(4 + 10e^{-\frac{38600}{T}} + 6e^{-\frac{58200}{T}}\right)$$

$$\ln Q_p(N^+) = \frac{5}{2} \ln T + 0.30 + \ln\left(1 + 3e^{-\frac{70.6}{T}} + 5e^{-\frac{188.9}{T}} + 5e^{-\frac{22000}{T}} + e^{-\frac{47000}{T}} + 5e^{-\frac{67900}{T}}\right)$$

$$\ln Q_p(e^-) = \frac{5}{2} \ln T - 14.24$$

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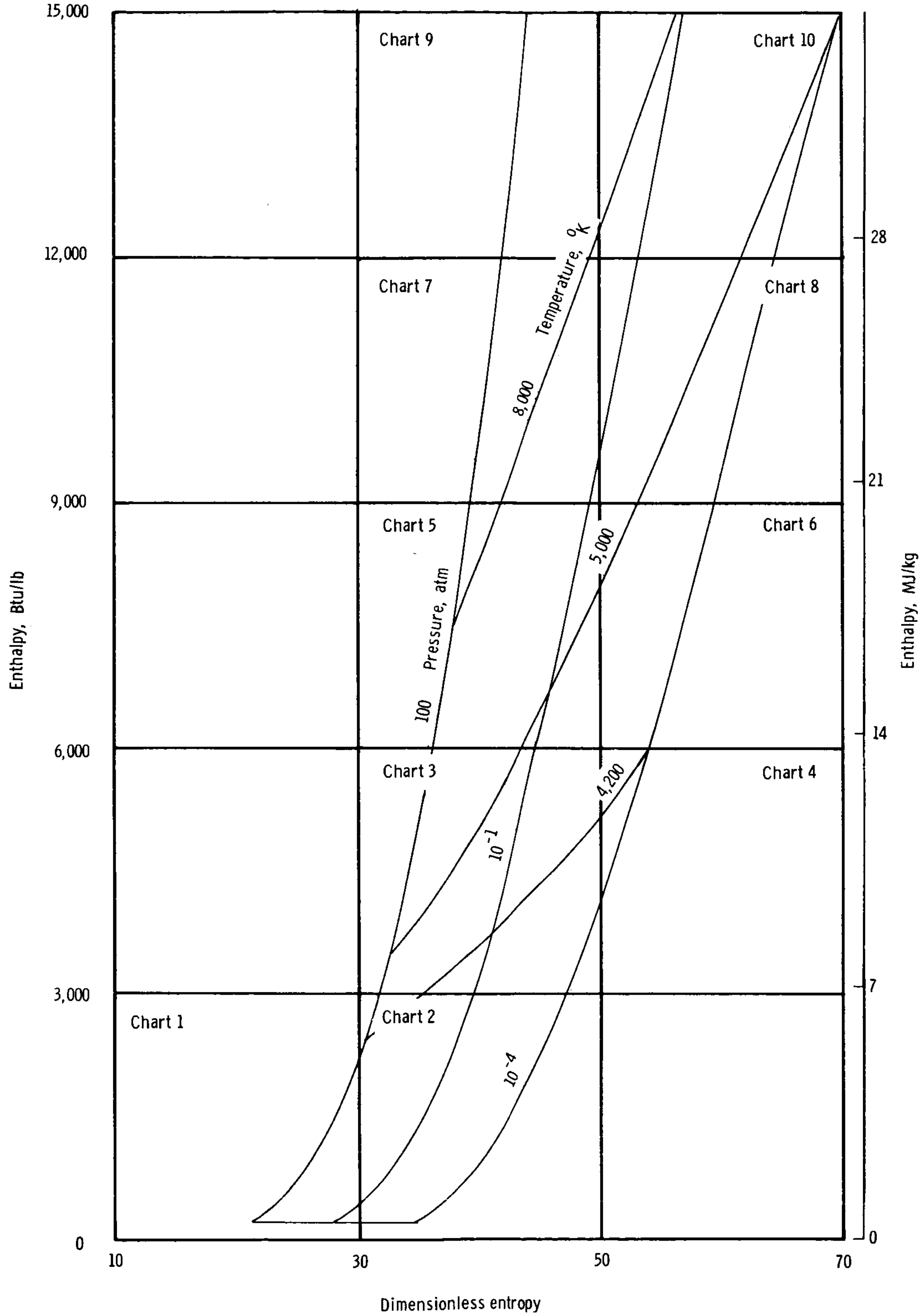
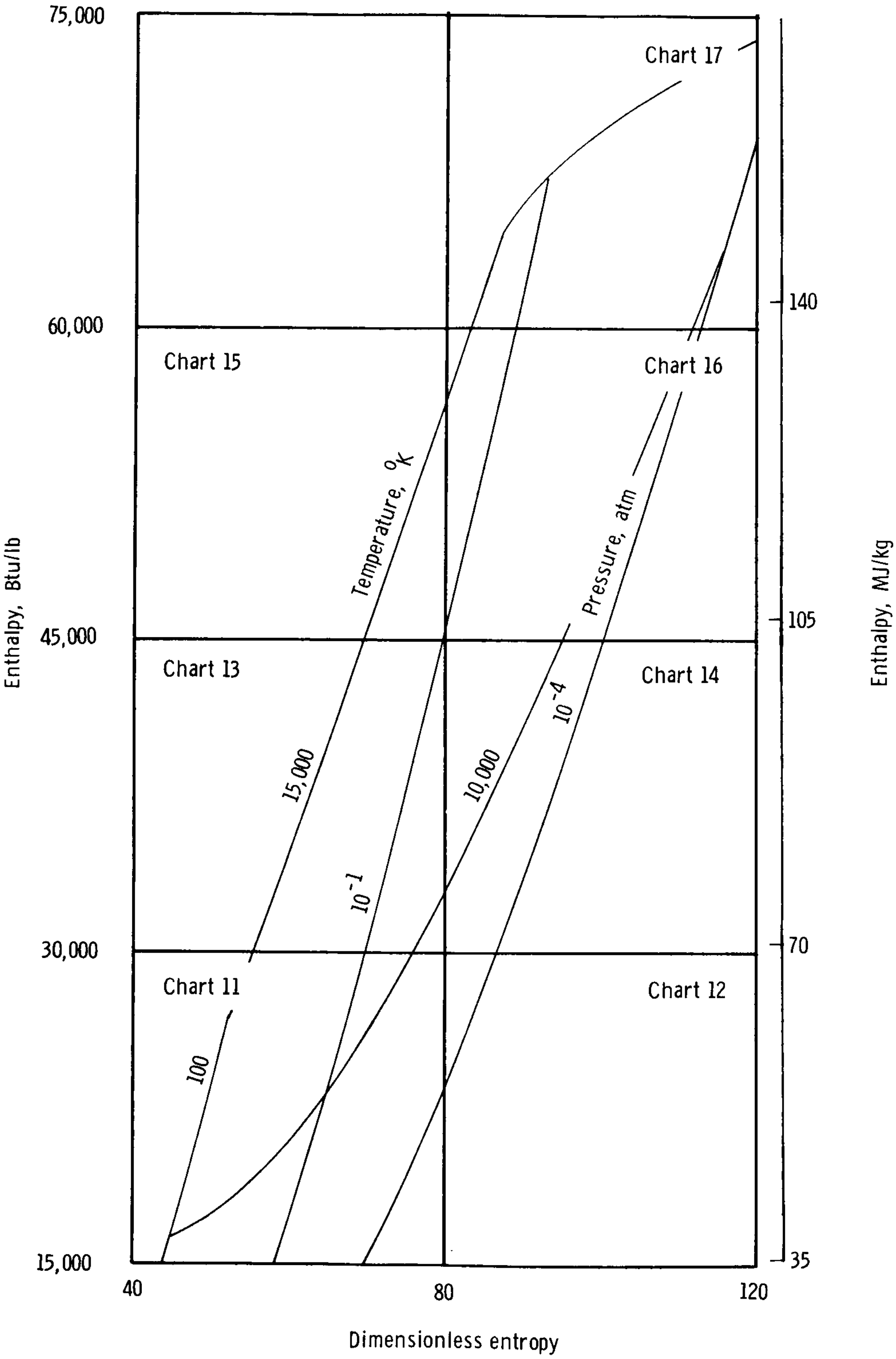
TABLE I.- PARTITION-FUNCTION CONSTANTS

Particle	Molecular weight, M_i, g/mol	Rotational constant, $\frac{\alpha h^2}{8\pi^2 Ik}$, °K	Vibrational constant, $h\nu/k$, °K	Dissociation energy, D/k, °K	Electronic degeneracy, g_n	Electronic energy, ϵ_n/k, °K	Ionization energy, I/k, °K
N_2	28	5.78	3390	113,200	1	0	
O_2	32	4.16	2270	59,000	3	0	
					2	11,390	
					1	18,990	
O	16				5	0	158,000
					3	228	
					1	326	
					5	22,800	
					1	48,600	
N	14				4	0	168,800
					10	27,700	
					6	41,500	
O^+	16				4	0	
					10	38,600	
					6	58,200	
N^+	14				1	0	
					3	70.6	
					5	188.9	
					5	22,000	
					1	47,000	
					5	67,900	
e^-	$\frac{1}{1820}$				2	0	



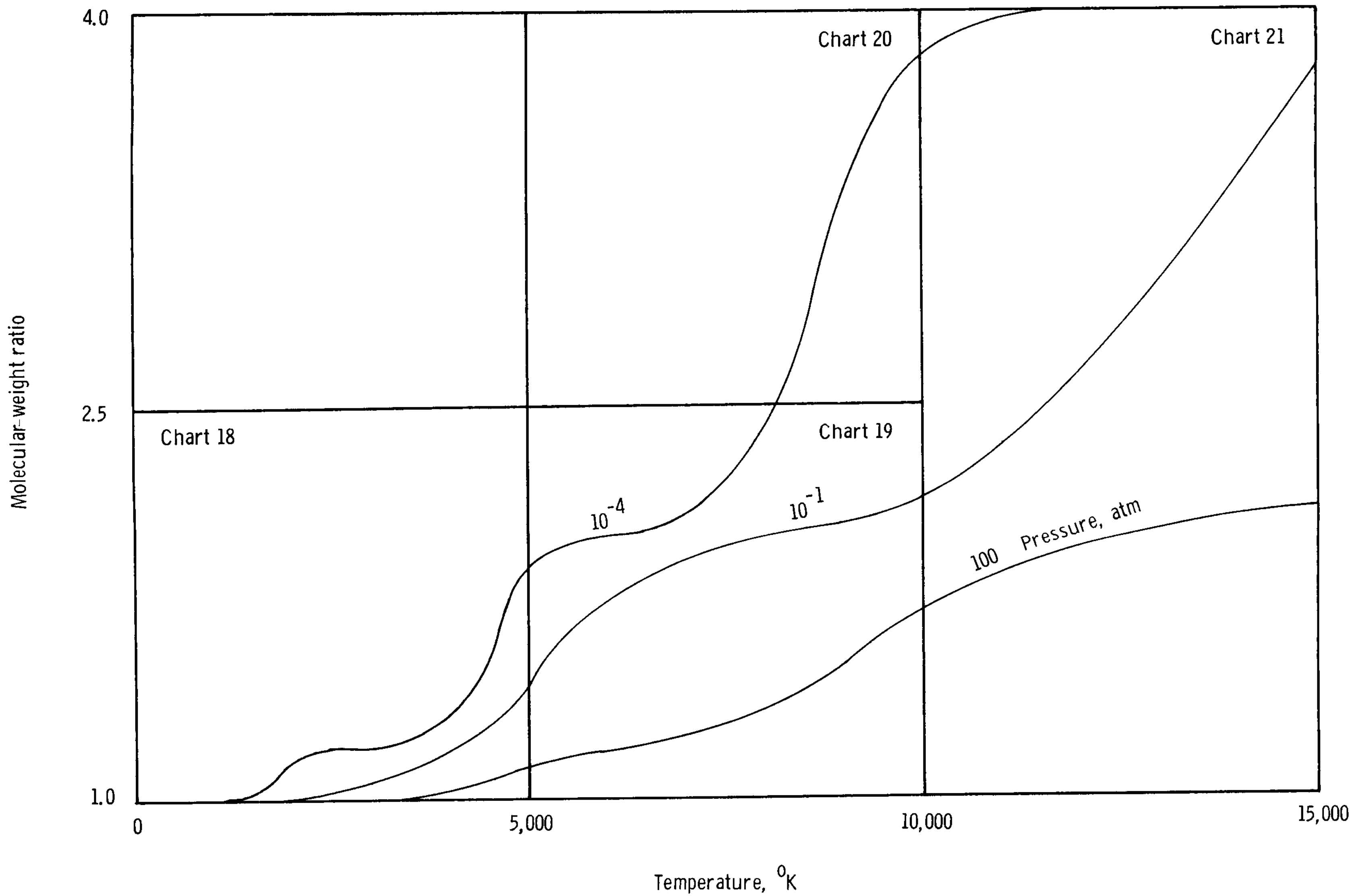
(a) Enthalpy as a function of entropy.

Figure 1.- Key to thermodynamic charts.



(a) Concluded.

Figure 1.- Continued.



(b) Molecular weight as a function of temperature.

Figure 1.- Concluded.

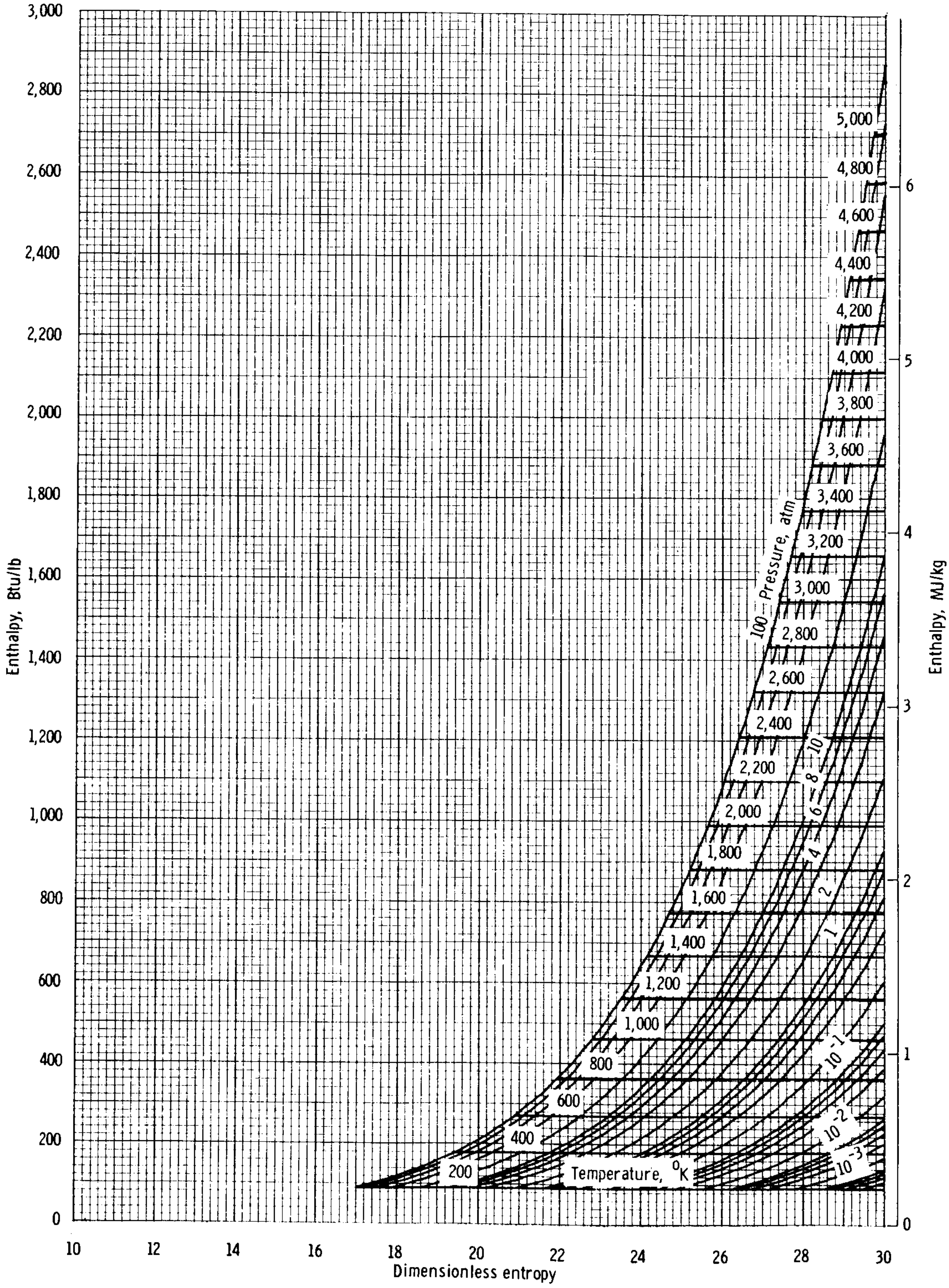


Chart 1

Figure 2.- Thermodynamic charts for 100 percent N_2.

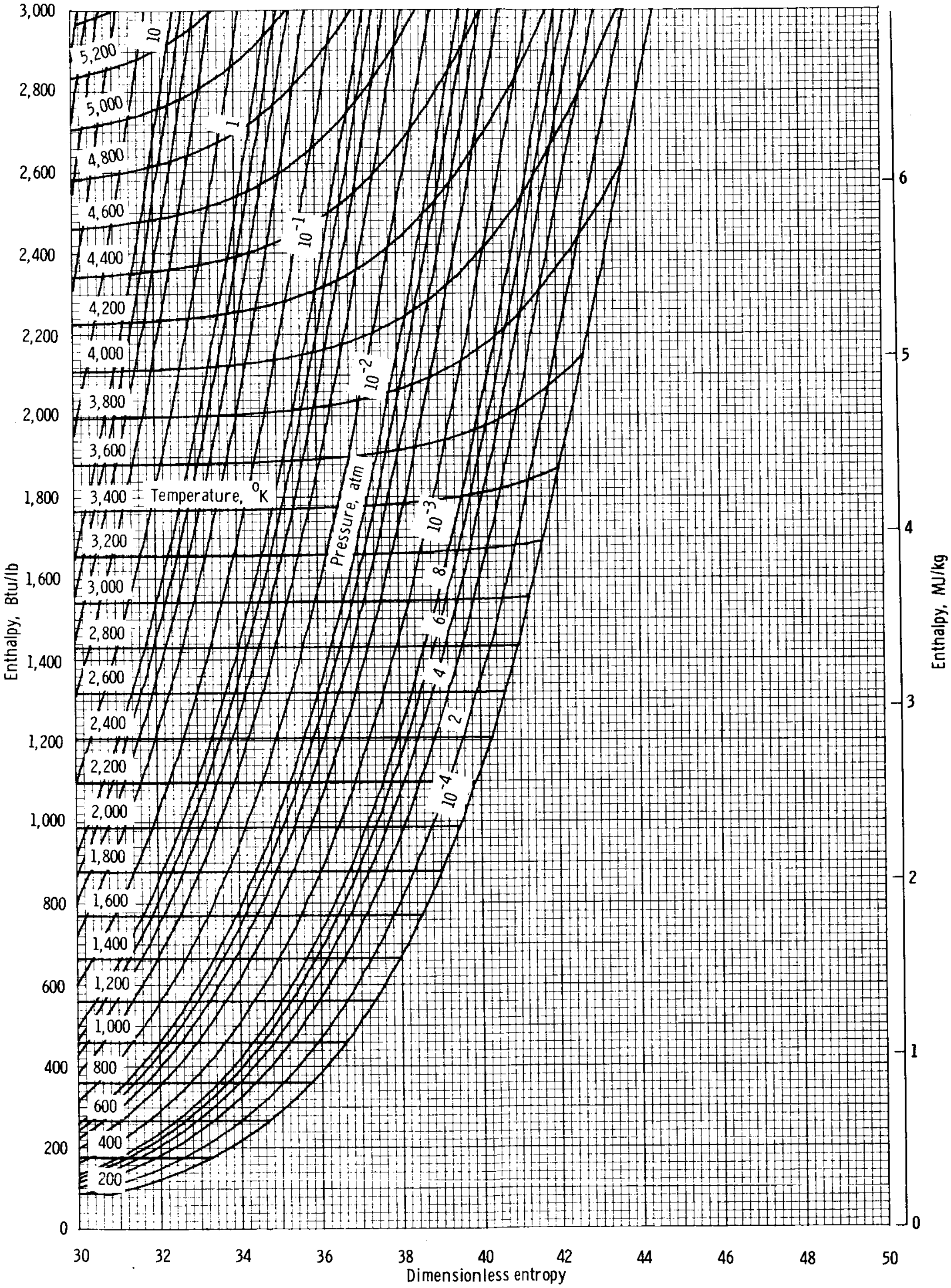


Chart 2

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

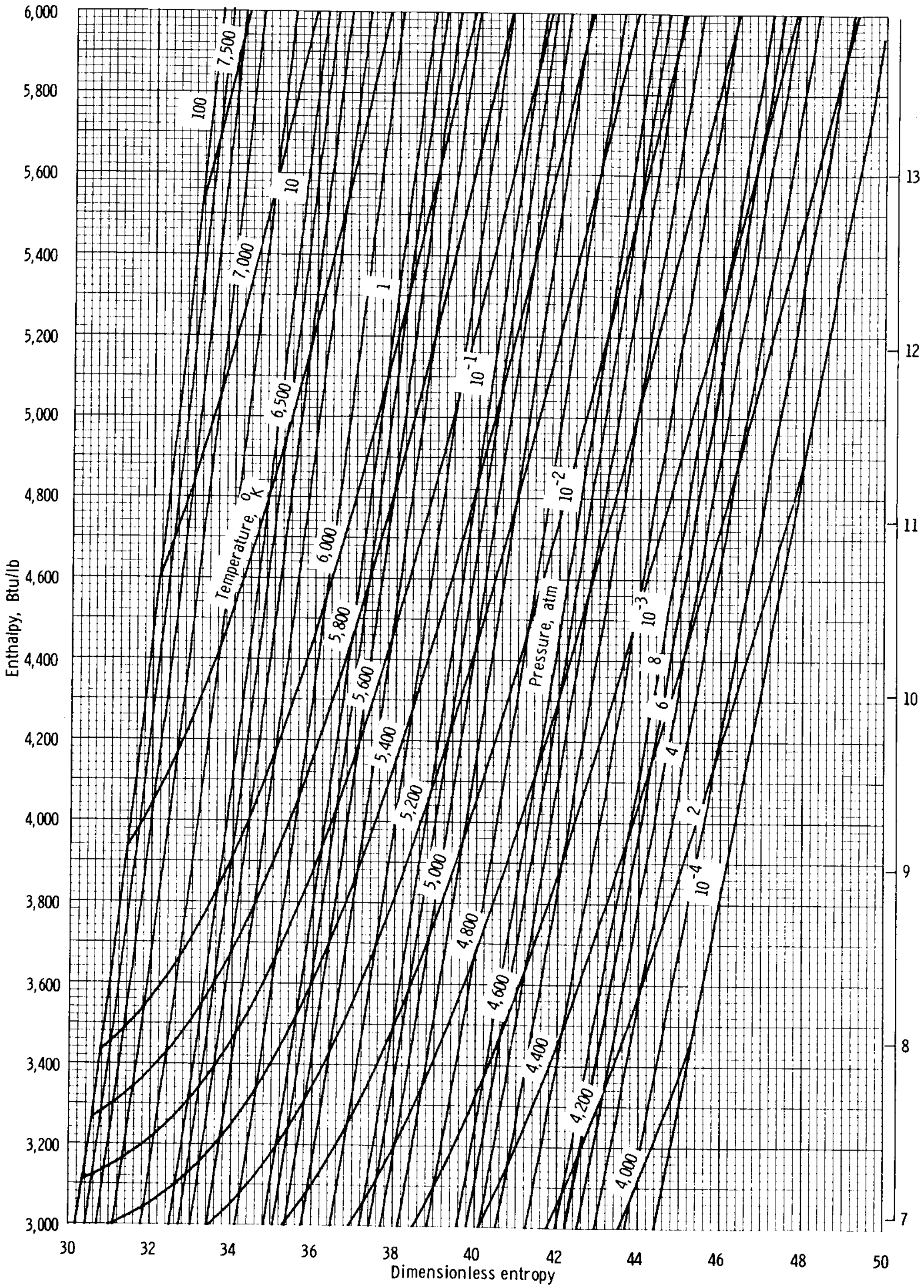


Chart 3

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

NOTE: No data appear on chart 4 for this composition.

Chart 4

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

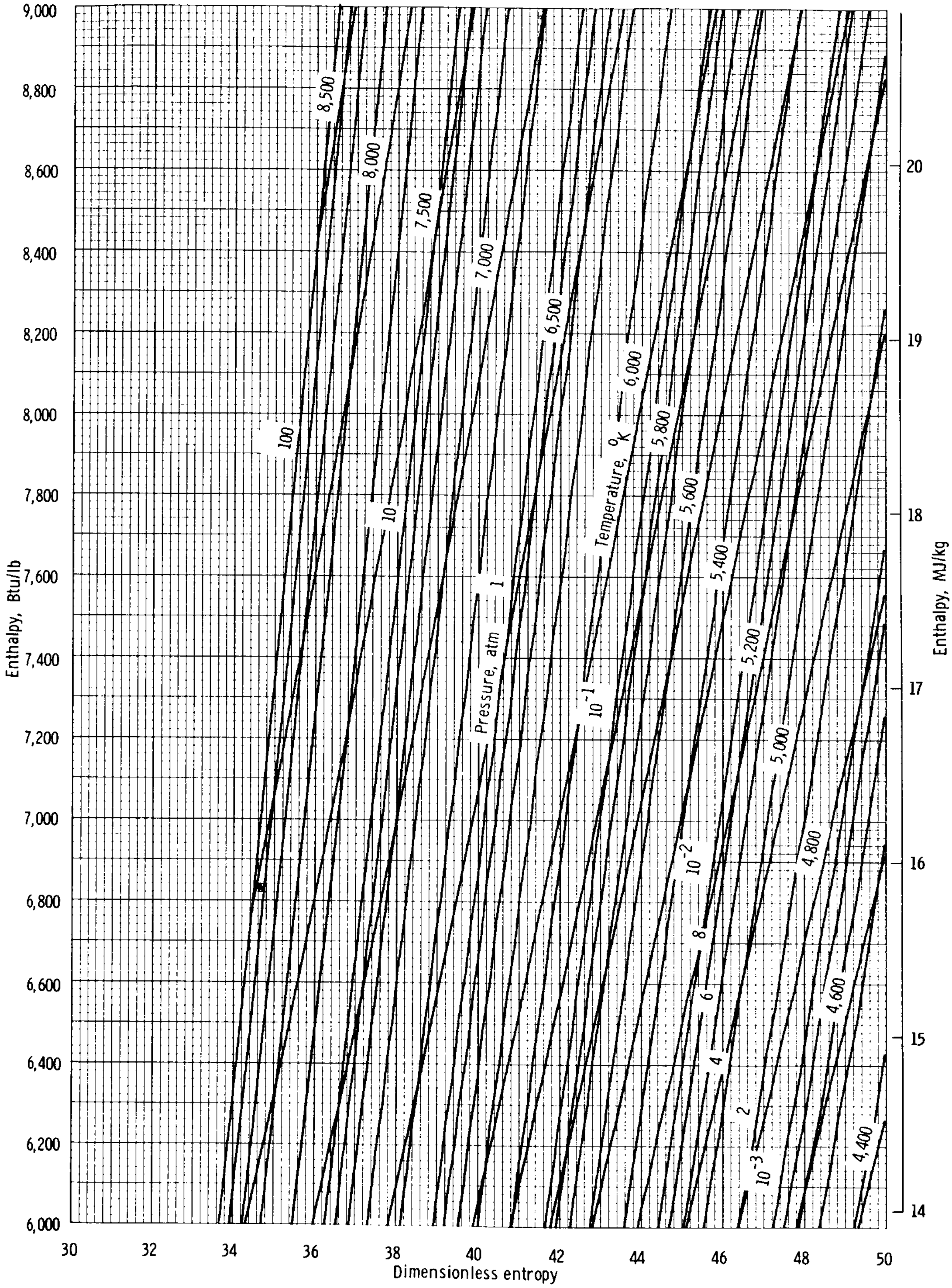


Chart 5

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

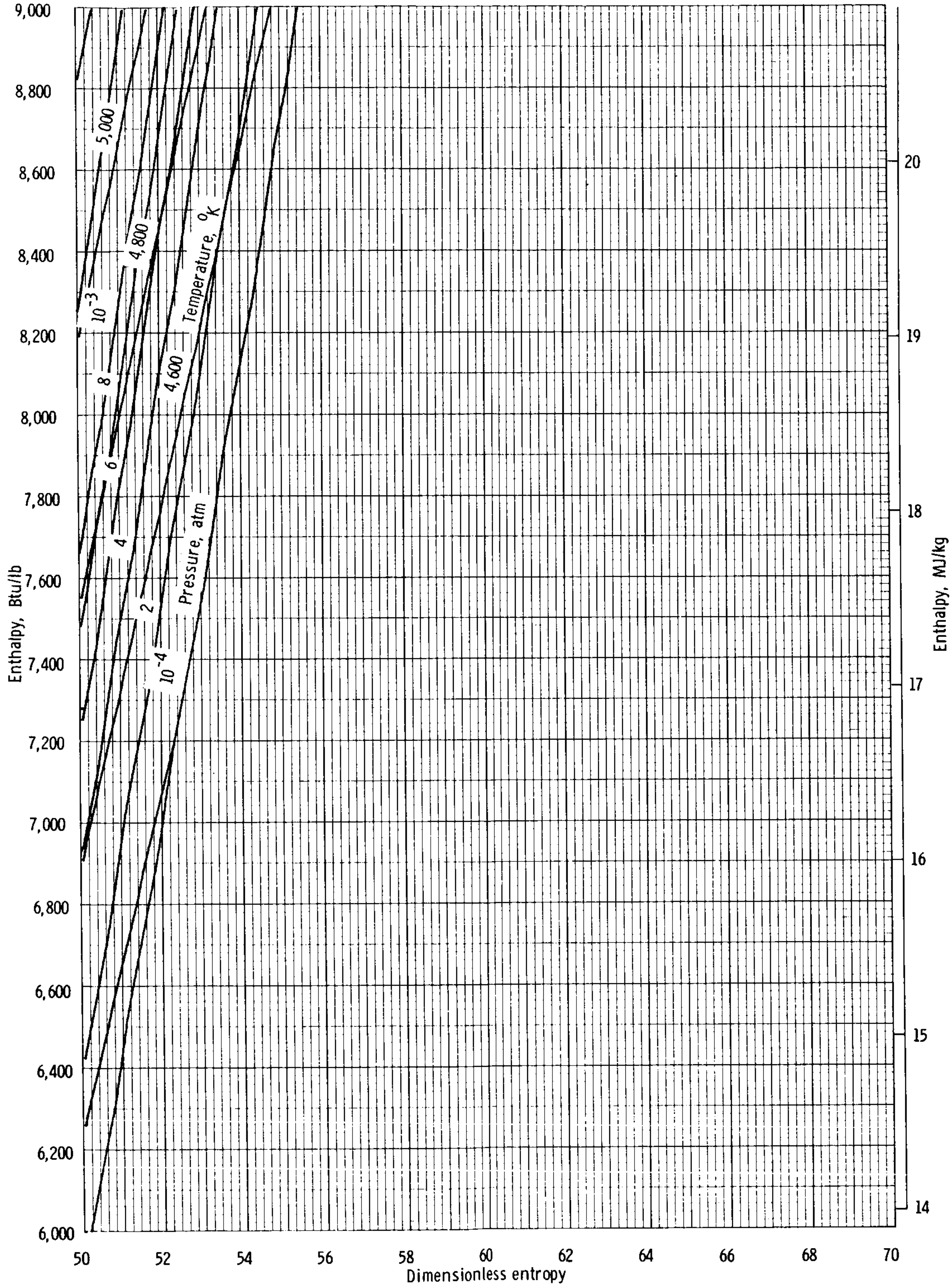


Chart 6

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

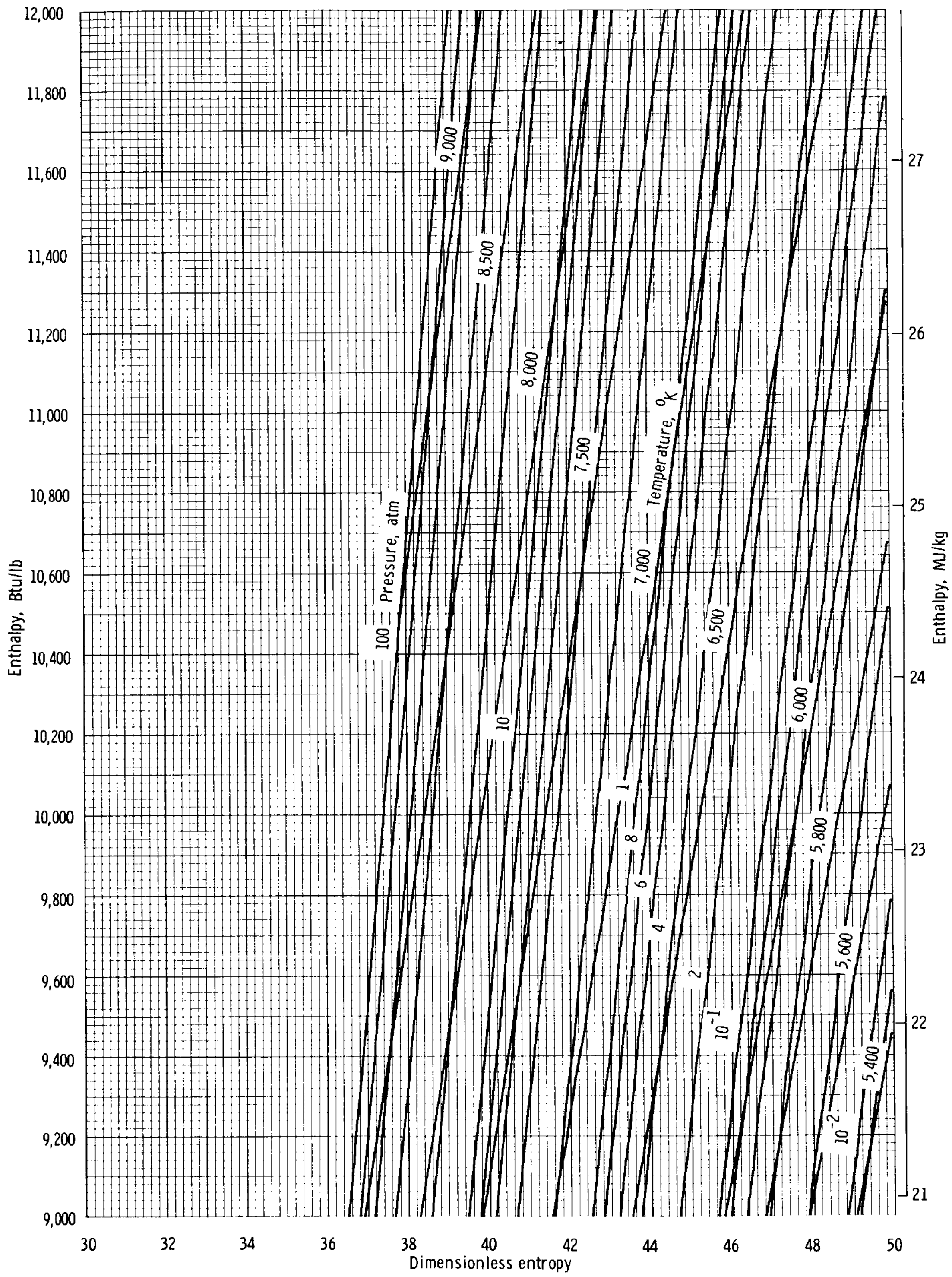


Chart 7

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

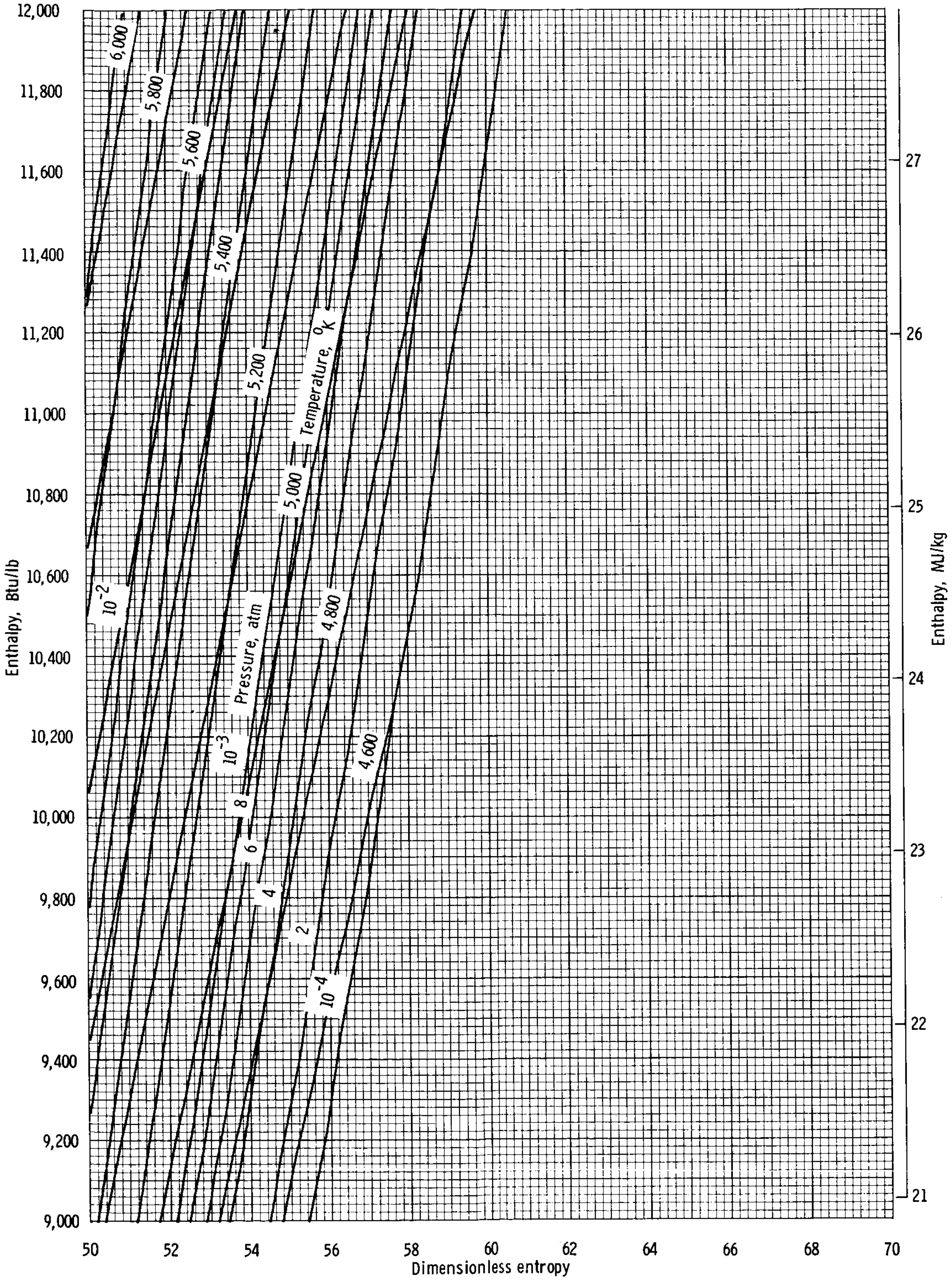


Chart 8

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

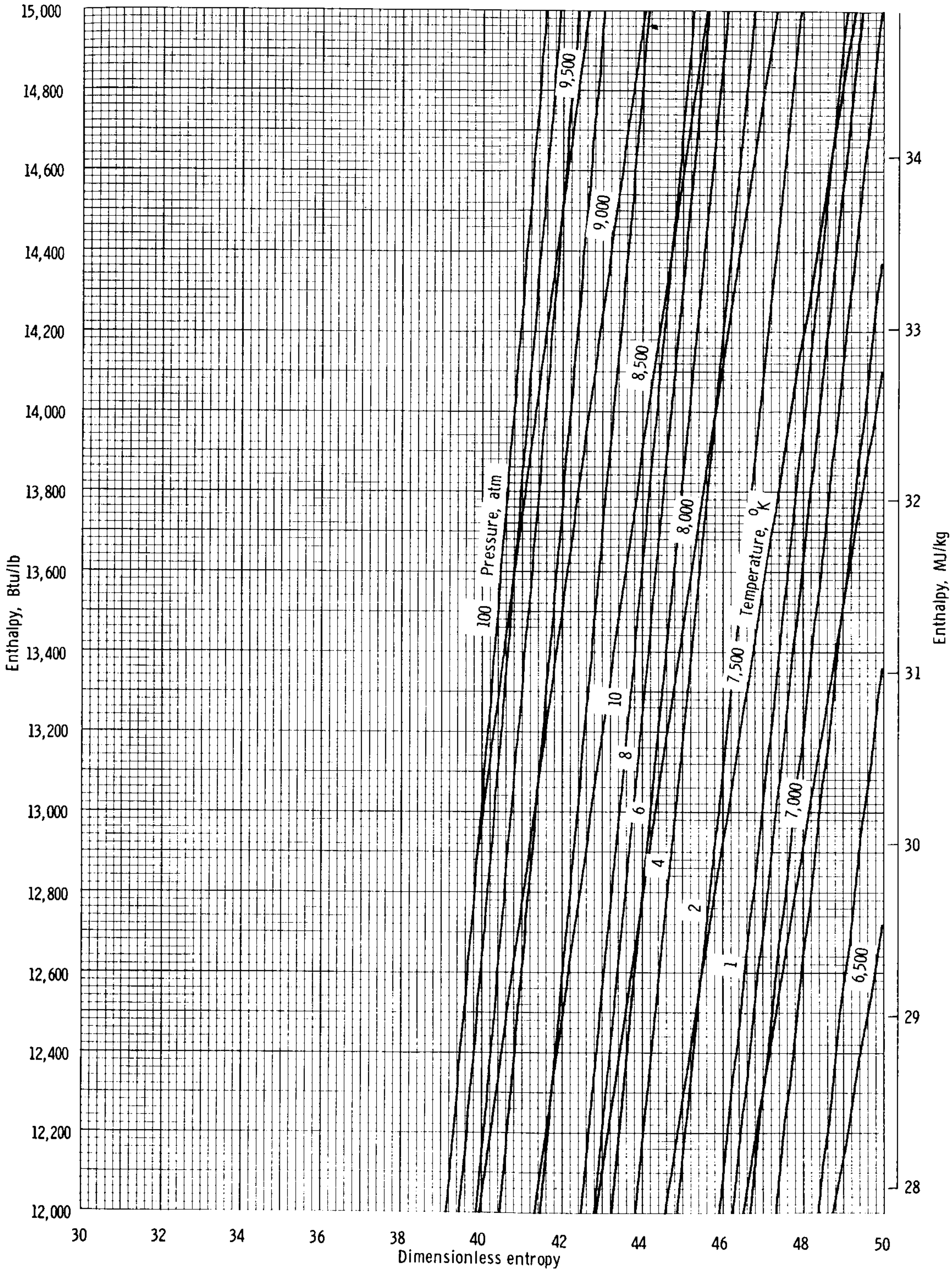


Chart 9

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

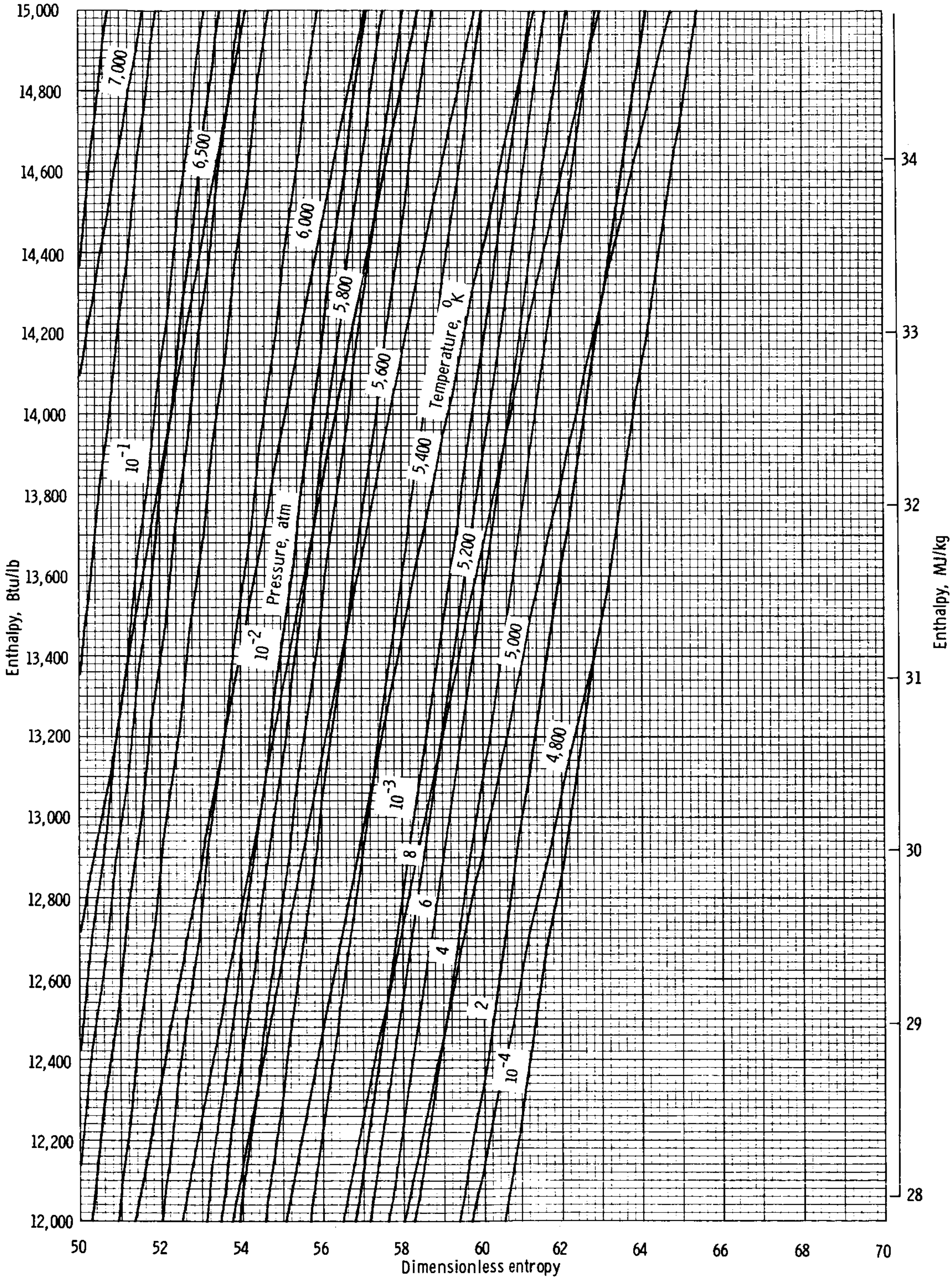


Chart 10

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

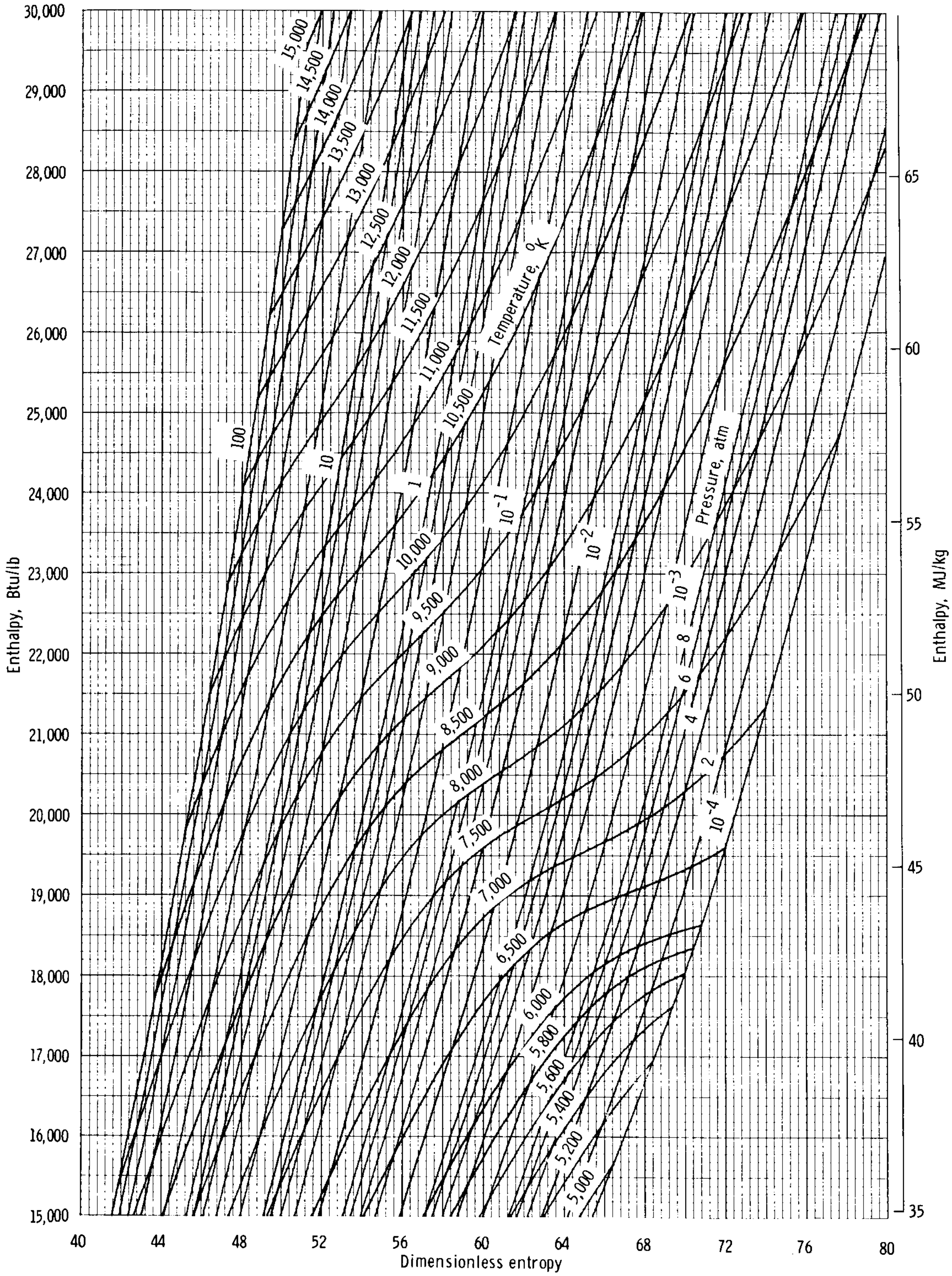


Chart 11

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

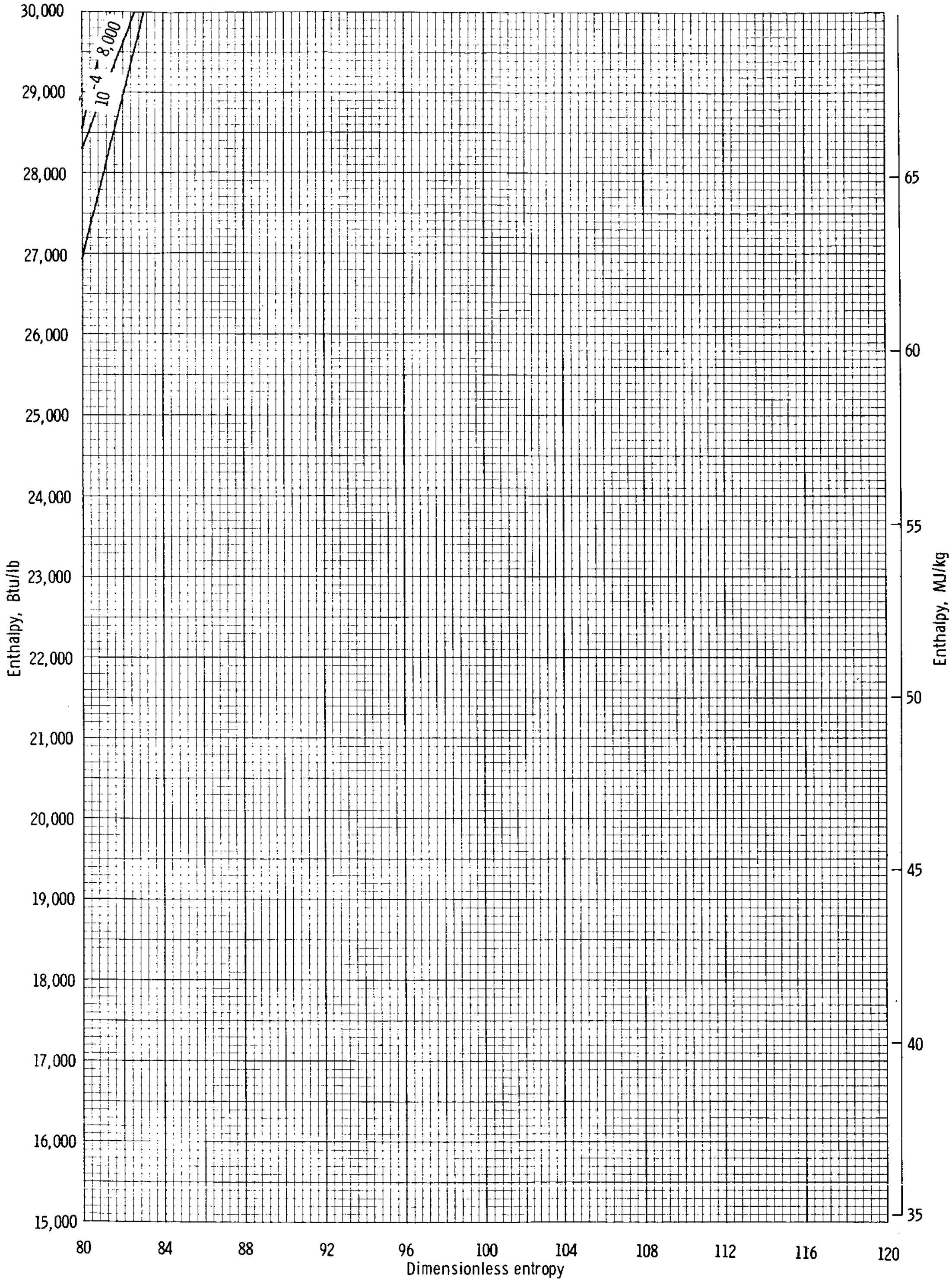


Chart 12

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

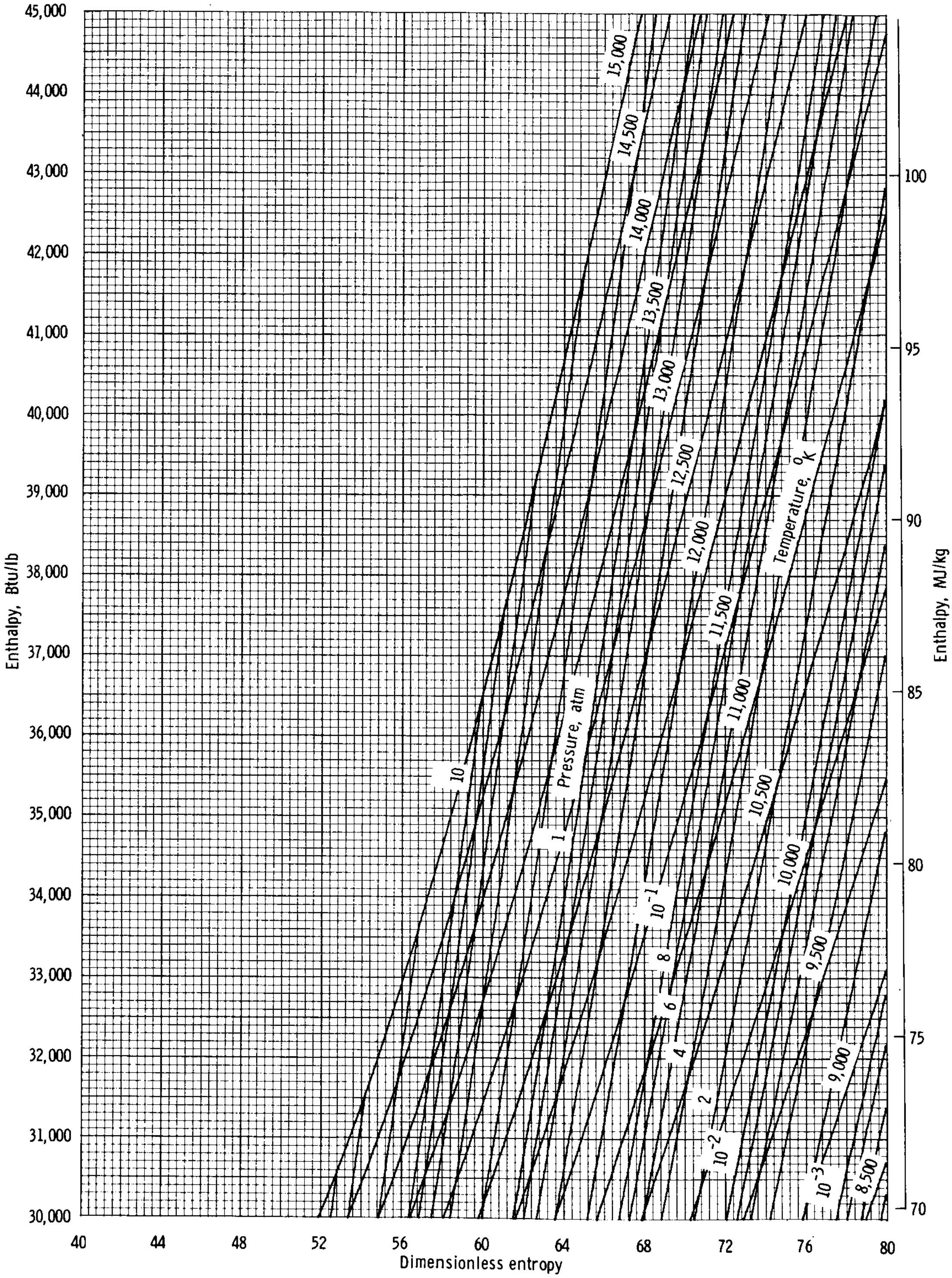


Chart 13

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

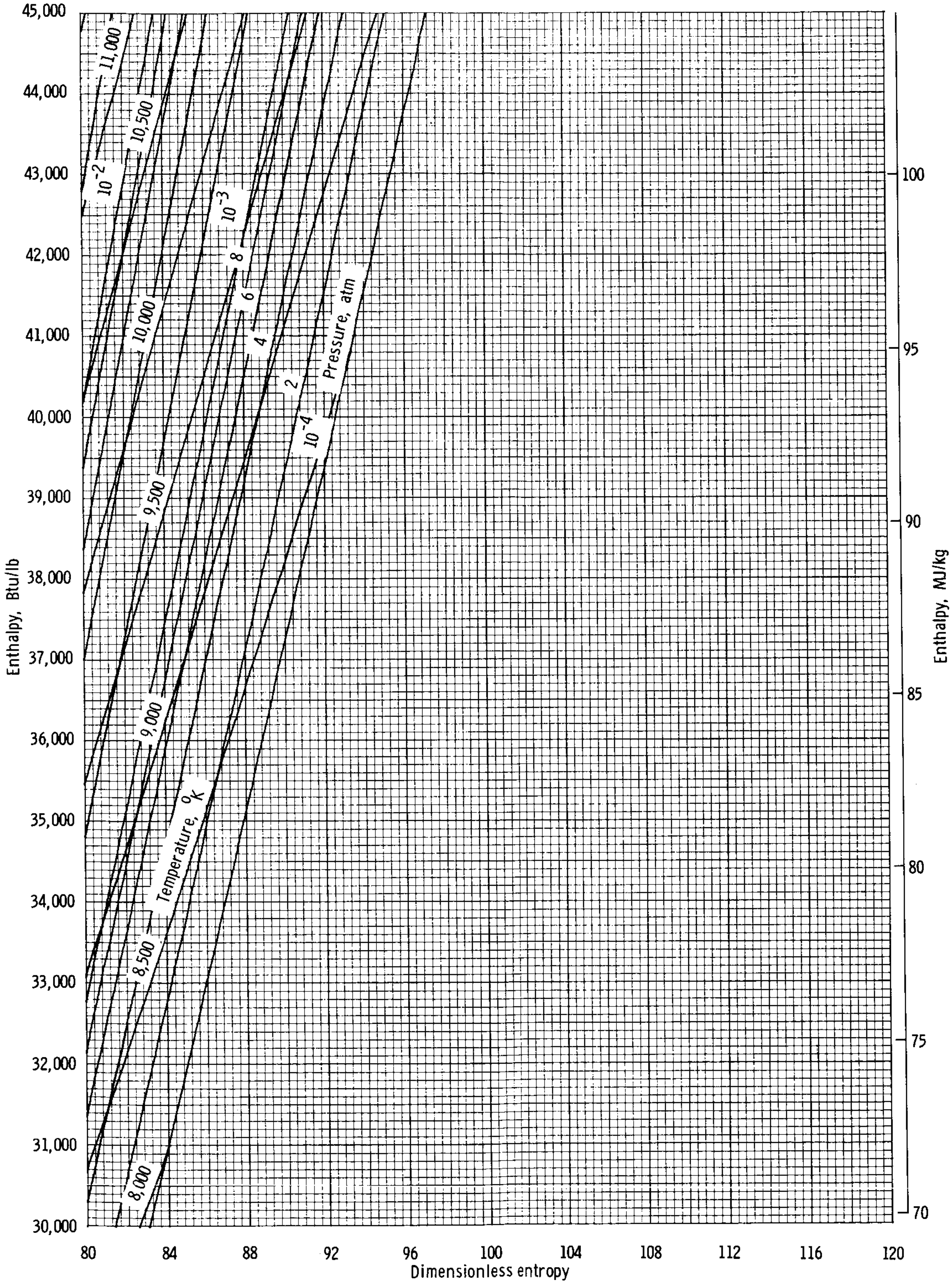


Chart 14

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

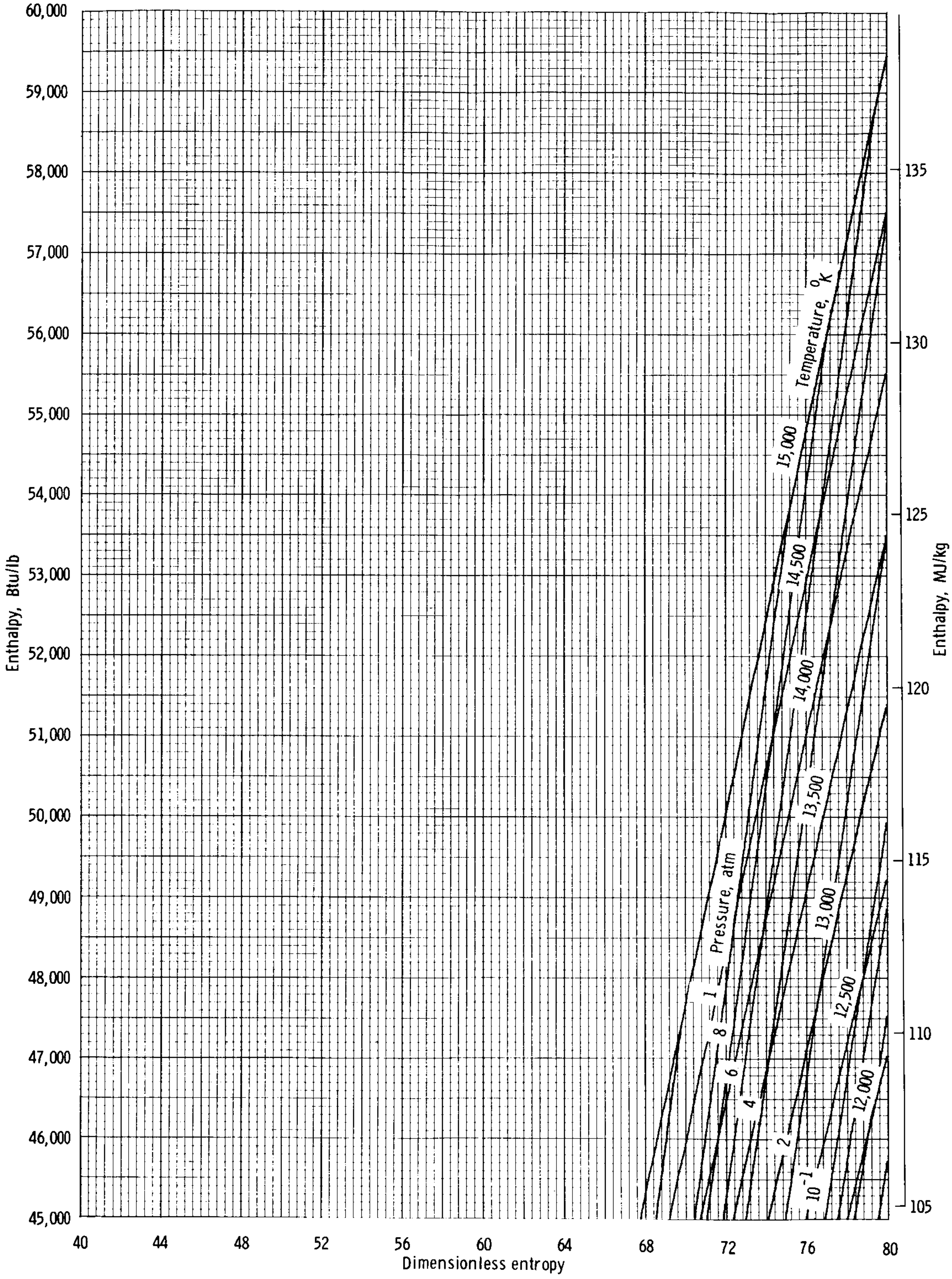


Chart 15

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

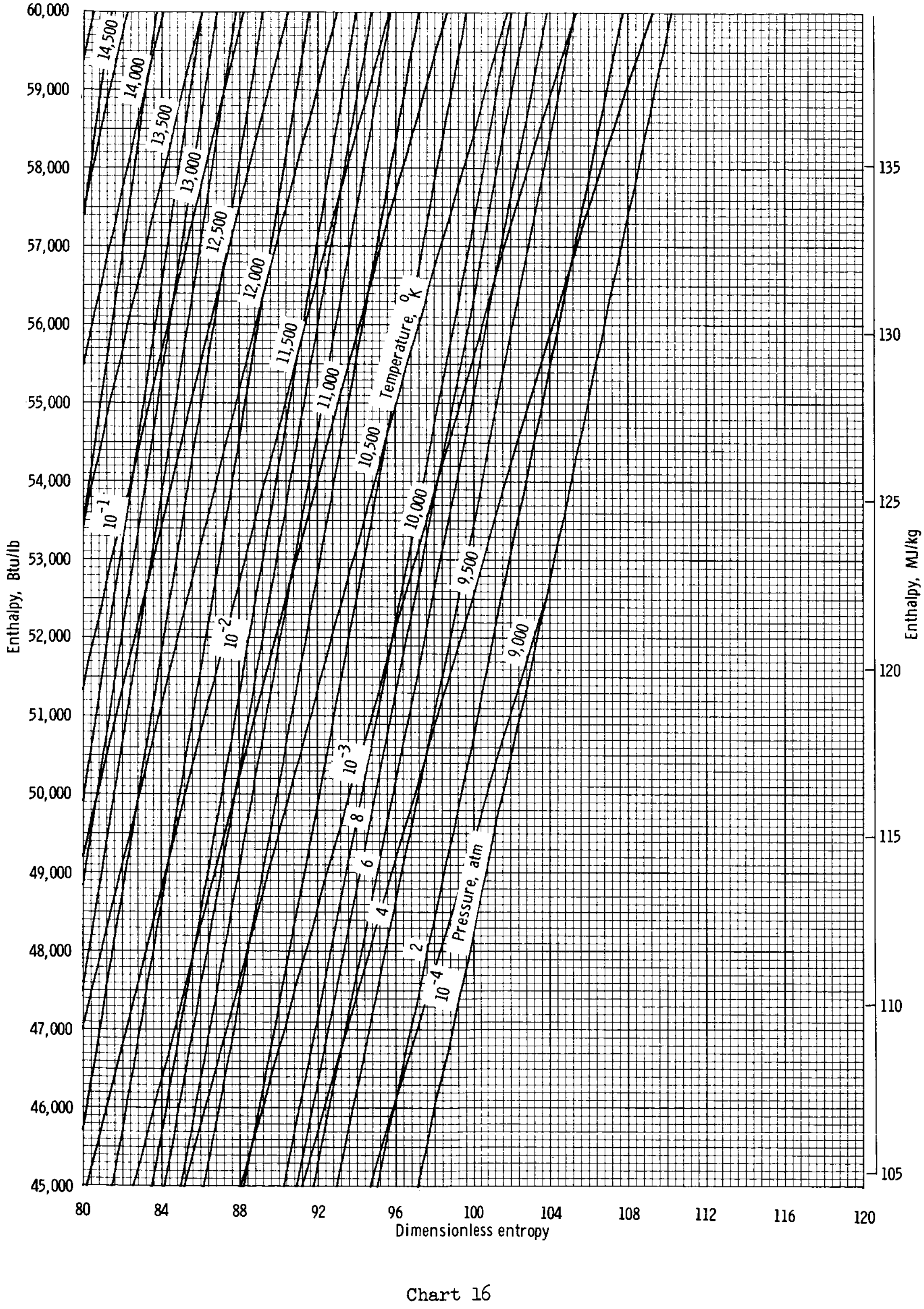


Chart 16

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

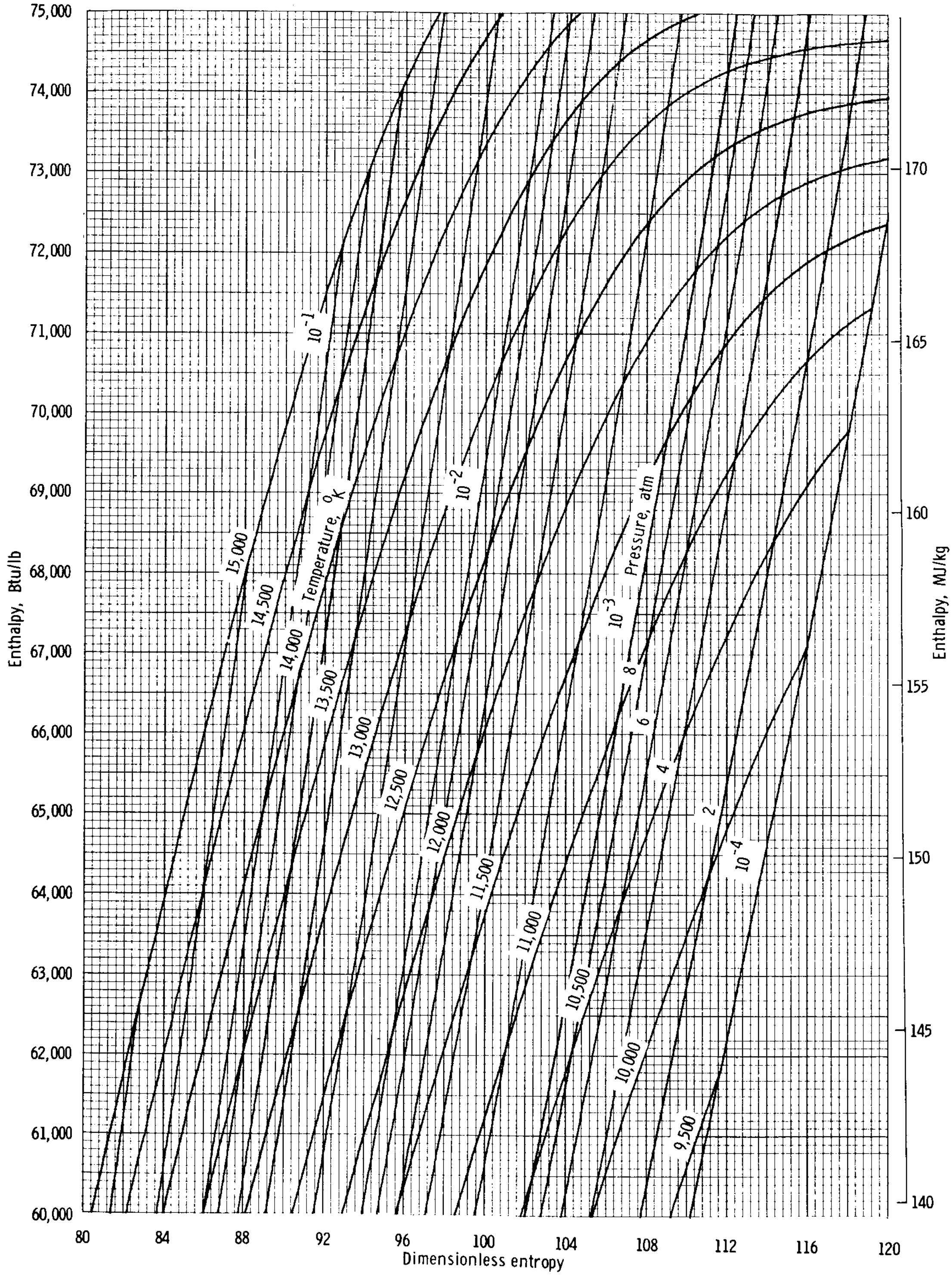


Chart 17

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

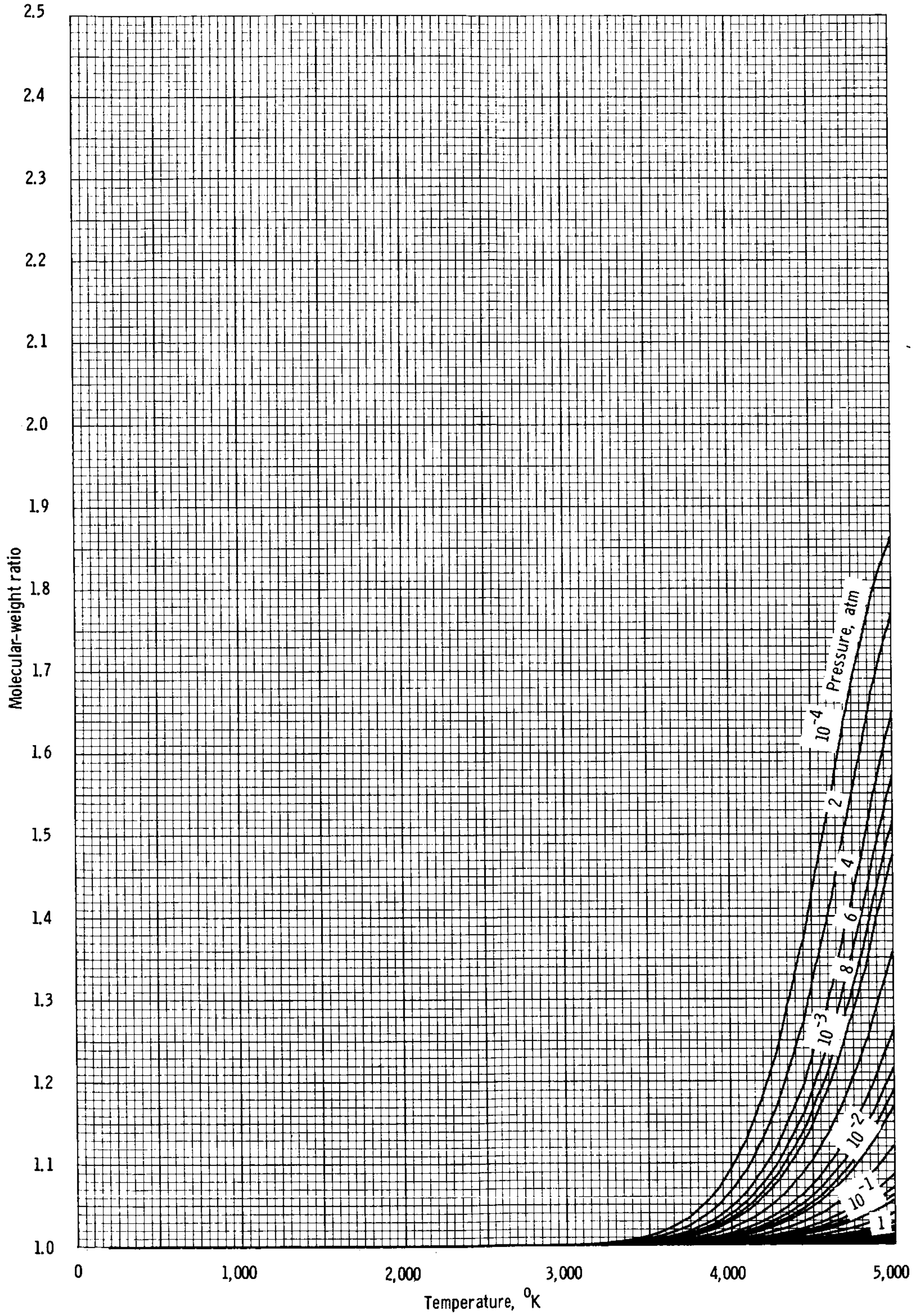


Chart 18

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

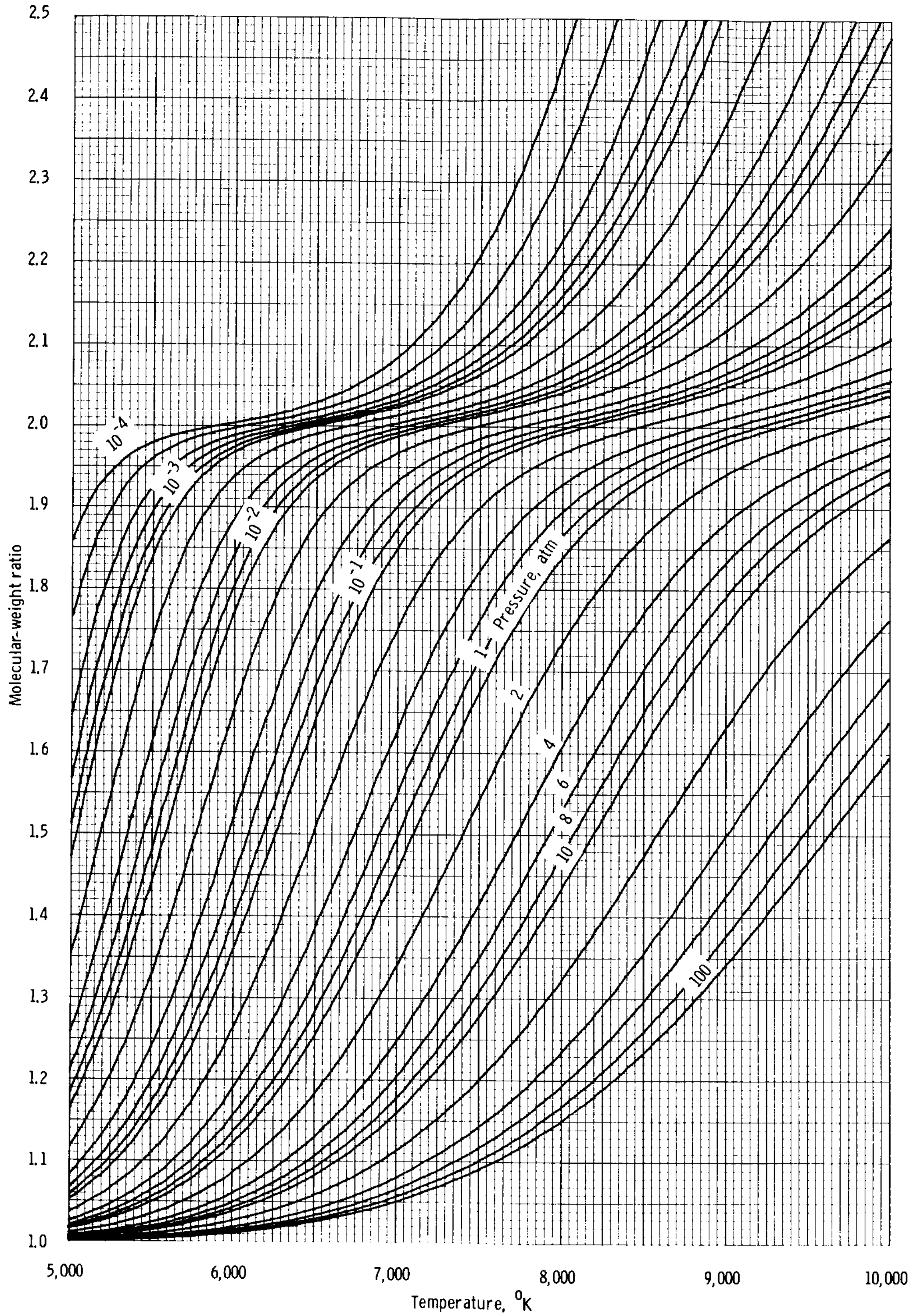


Chart 19

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

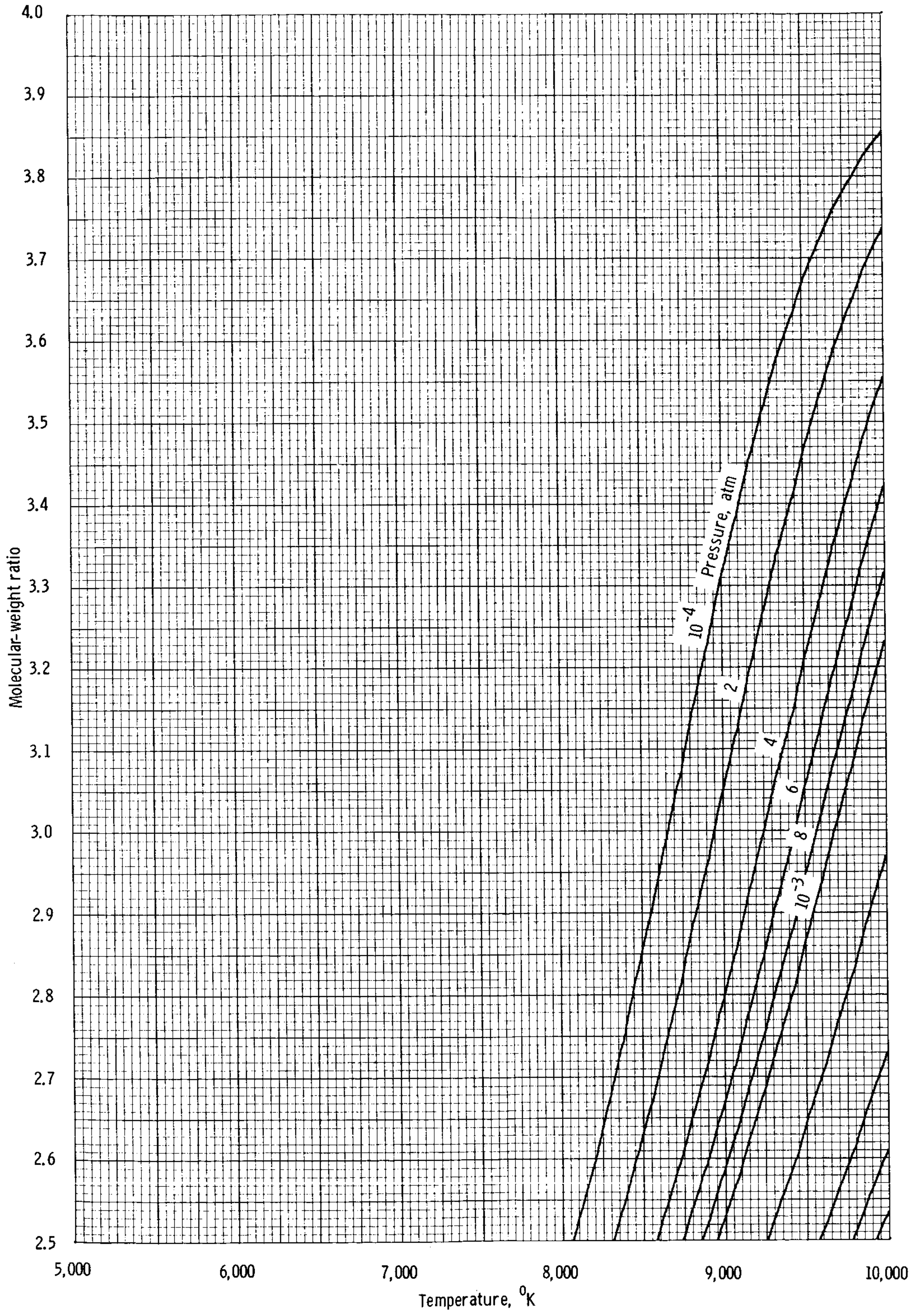


Chart 20

Figure 2.- Thermodynamic charts for 100 percent N_2. Continued.

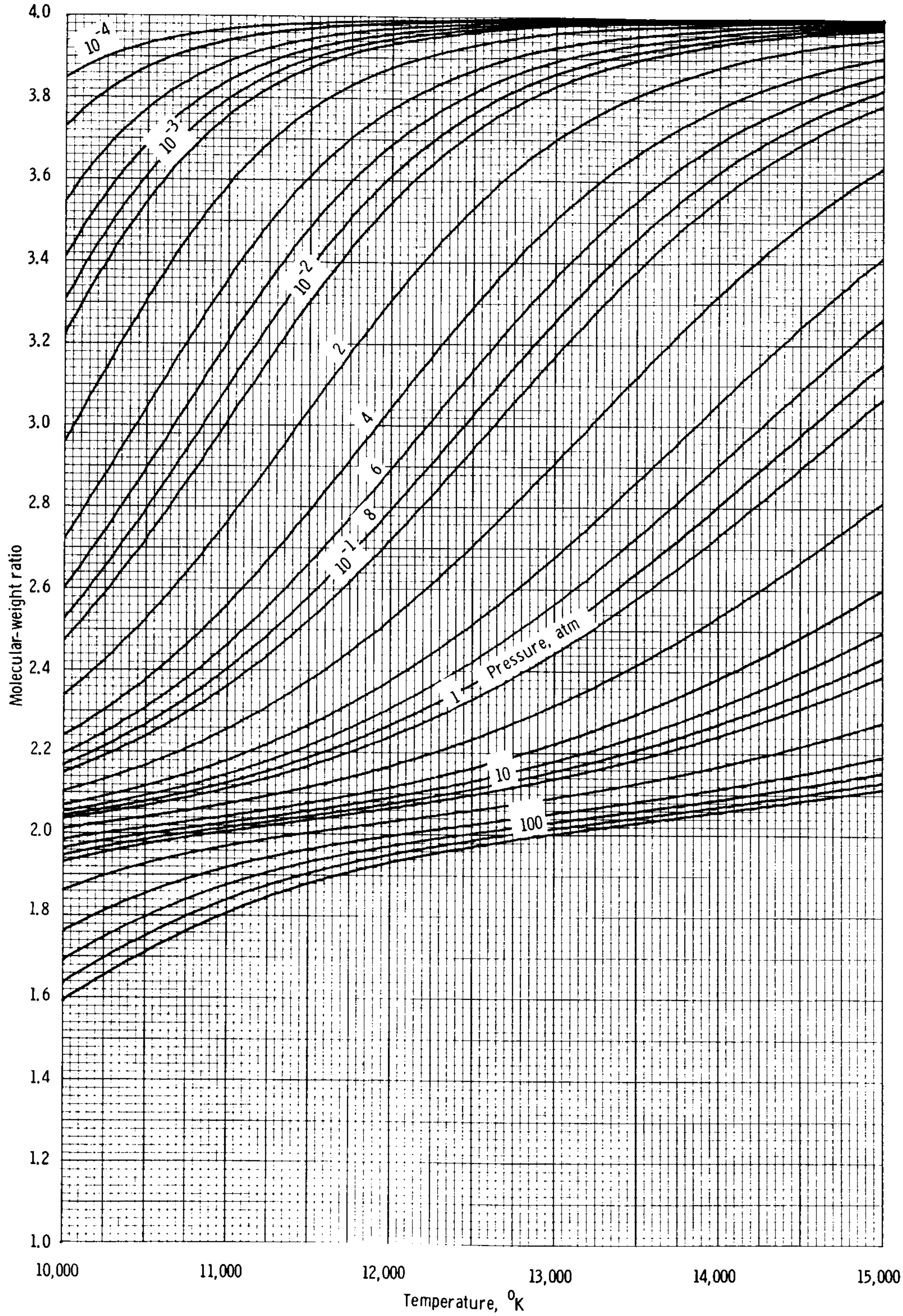


Chart 21

Figure 2.- Thermodynamic charts for 100 percent N_2. Concluded.

TABLE II.- THERMODYNAMIC PROPERTIES OF 100 PERCENT N_2

(a) Ratio of specific heats γ

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3976	1.3976	1.3976	1.3976	1.3976	1.3976	1.3976
600	1.3827	1.3827	1.3827	1.3827	1.3827	1.3827	1.3827
800	1.3614	1.3614	1.3614	1.3614	1.3614	1.3614	1.3614
1,000	1.3431	1.3431	1.3431	1.3431	1.3431	1.3431	1.3431
1,200	1.3295	1.3295	1.3295	1.3295	1.3295	1.3295	1.3295
1,400	1.3198	1.3198	1.3198	1.3198	1.3198	1.3198	1.3198
1,600	1.3128	1.3128	1.3128	1.3128	1.3128	1.3128	1.3128
1,800	1.3077	1.3077	1.3077	1.3077	1.3077	1.3077	1.3077
2,000	1.3038	1.3038	1.3038	1.3038	1.3038	1.3038	1.3038
2,200	1.3009	1.3009	1.3009	1.3009	1.3009	1.3009	1.3008
2,400	1.2986	1.2986	1.2986	1.2986	1.2985	1.2984	1.2981
2,600	1.2968	1.2968	1.2967	1.2967	1.2965	1.2960	1.2942
2,800	1.2953	1.2953	1.2952	1.2950	1.2943	1.2920	1.2852
3,000	1.2941	1.2940	1.2938	1.2930	1.2906	1.2834	1.2633
3,200	1.2930	1.2928	1.2921	1.2899	1.2834	1.2648	1.2225
3,400	1.2920	1.2915	1.2898	1.2845	1.2692	1.2327	1.1733
3,600	1.2910	1.2898	1.2860	1.2747	1.2458	1.1922	1.1369
3,800	1.2898	1.2873	1.2797	1.2590	1.2146	1.1568	1.1240
4,000	1.2883	1.2836	1.2701	1.2372	1.1828	1.1368	1.1347
4,200	1.2861	1.2781	1.2564	1.2119	1.1582	1.1346	1.1655
4,400	1.2832	1.2704	1.2393	1.1877	1.1455	1.1493	1.2051
4,600	1.2791	1.2603	1.2202	1.1691	1.1457	1.1779	1.2256
4,800	1.2739	1.2481	1.2017	1.1584	1.1580	1.2119	1.2073
5,000	1.2673	1.2346	1.1862	1.1567	1.1806	1.2341	1.1777
5,200	1.2595	1.2209	1.1756	1.1636	1.2091	1.2292	1.1736
5,400	1.2508	1.2082	1.1705	1.1783	1.2351	1.2052	1.2028
5,600	1.2415	1.1978	1.1714	1.1993	1.2475	1.1870	1.2455
5,800	1.2322	1.1904	1.1780	1.2233	1.2406	1.1896	1.2665
6,000	1.2234	1.1864	1.1899	1.2453	1.2219	1.2115	1.2544
6,500	1.2073	1.1928	1.2349	1.2567	1.2036	1.2480	1.1842
7,000	1.2034	1.2197	1.2734	1.2230	1.2355	1.2035	1.1518
7,500	1.2131	1.2580	1.2696	1.2208	1.2252	1.1689	1.1617
8,000	1.2348	1.2890	1.2429	1.2334	1.1943	1.1651	1.2008
8,500	1.2642	1.2944	1.2327	1.2233	1.1785	1.1866	1.2411
9,000	1.2934	1.2772	1.2361	1.2052	1.1822	1.2235	1.2410
9,500	1.3130	1.2585	1.2340	1.1955	1.2021	1.2558	1.2123
10,000	1.3167	1.2502	1.2252	1.1979	1.2325	1.2601	1.2114
10,500	1.3069	1.2490	1.2178	1.2112	1.2630	1.2404	1.2623
11,000	1.2923	1.2479	1.2164	1.2330	1.2802	1.2285	1.3528
11,500	1.2808	1.2451	1.2219	1.2592	1.2774	1.2467	1.4464
12,000	1.2748	1.2427	1.2338	1.2840	1.2637	1.2975	1.5143
12,500	1.2730	1.2428	1.2509	1.3008	1.2560	1.3687	1.5538
13,000	1.2730	1.2463	1.2714	1.3058	1.2660	1.4403	1.5746
13,500	1.2735	1.2535	1.2929	1.3009	1.2963	1.4970	1.5852
14,000	1.2745	1.2642	1.3125	1.2930	1.3427	1.5356	1.5905
14,500	1.2764	1.2777	1.3275	1.2898	1.3963	1.5597	1.5932
15,000	1.2798	1.2934	1.3361	1.2963	1.4478	1.5740	1.5945

TABLE II.- THERMODYNAMIC PROPERTIES OF 100 PERCENT N_2 - Concluded

(b) Dimensionless speed-of-sound parameter $a^2\rho/p$

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3976	1.3976	1.3976	1.3976	1.3976	1.3976	1.3976
600	1.3827	1.3827	1.3827	1.3827	1.3827	1.3827	1.3827
800	1.3614	1.3614	1.3614	1.3614	1.3614	1.3614	1.3614
1,000	1.3431	1.3431	1.3431	1.3431	1.3431	1.3431	1.3431
1,200	1.3295	1.3295	1.3295	1.3295	1.3295	1.3295	1.3295
1,400	1.3198	1.3198	1.3198	1.3198	1.3198	1.3198	1.3198
1,600	1.3128	1.3128	1.3128	1.3128	1.3128	1.3128	1.3128
1,800	1.3077	1.3077	1.3077	1.3077	1.3077	1.3077	1.3077
2,000	1.3038	1.3038	1.3038	1.3038	1.3038	1.3038	1.3038
2,200	1.3009	1.3009	1.3009	1.3009	1.3009	1.3009	1.3008
2,400	1.2986	1.2986	1.2986	1.2986	1.2985	1.2984	1.2981
2,600	1.2968	1.2968	1.2967	1.2967	1.2965	1.2960	1.2942
2,800	1.2953	1.2953	1.2952	1.2950	1.2942	1.2920	1.2851
3,000	1.2941	1.2940	1.2938	1.2930	1.2906	1.2833	1.2628
3,200	1.2930	1.2928	1.2921	1.2899	1.2832	1.2644	1.2211
3,400	1.2920	1.2915	1.2897	1.2843	1.2688	1.2313	1.1692
3,600	1.2910	1.2898	1.2858	1.2743	1.2447	1.1888	1.1269
3,800	1.2898	1.2872	1.2795	1.2581	1.2121	1.1493	1.1018
4,000	1.2882	1.2834	1.2695	1.2354	1.1774	1.1211	1.0898
4,200	1.2860	1.2777	1.2553	1.2085	1.1479	1.1046	1.0857
4,400	1.2829	1.2697	1.2371	1.1814	1.1269	1.0965	1.0861
4,600	1.2787	1.2591	1.2165	1.1581	1.1137	1.0937	1.0897
4,800	1.2732	1.2461	1.1955	1.1402	1.1065	1.0943	1.0972
5,000	1.2662	1.2313	1.1764	1.1280	1.1035	1.0974	1.1118
5,200	1.2578	1.2158	1.1604	1.1203	1.1033	1.1032	1.1399
5,400	1.2482	1.2006	1.1481	1.1161	1.1053	1.1131	1.1860
5,600	1.2377	1.1867	1.1392	1.1144	1.1091	1.1300	1.2366
5,800	1.2269	1.1746	1.1332	1.1147	1.1150	1.1569	1.2609
6,000	1.2161	1.1648	1.1296	1.1166	1.1240	1.1928	1.2495
6,500	1.1920	1.1490	1.1279	1.1272	1.1680	1.2409	1.1747
7,000	1.1749	1.1431	1.1332	1.1502	1.2225	1.1944	1.1280
7,500	1.1650	1.1436	1.1445	1.1893	1.2158	1.1499	1.1090
8,000	1.1607	1.1484	1.1635	1.2179	1.1800	1.1267	1.1040
8,500	1.1605	1.1569	1.1900	1.2105	1.1527	1.1172	1.1062
9,000	1.1633	1.1693	1.2122	1.1880	1.1375	1.1155	1.1146
9,500	1.1685	1.1859	1.2164	1.1686	1.1308	1.1188	1.1330
10,000	1.1758	1.2041	1.2067	1.1561	1.1295	1.1268	1.1718
10,500	1.1853	1.2181	1.1937	1.1494	1.1321	1.1414	1.2434
11,000	1.1970	1.2237	1.1828	1.1470	1.1380	1.1676	1.3435
11,500	1.2100	1.2217	1.1753	1.1478	1.1476	1.2121	1.4417
12,000	1.2227	1.2161	1.1710	1.1511	1.1625	1.2780	1.5118
12,500	1.2331	1.2099	1.1694	1.1566	1.1854	1.3575	1.5525
13,000	1.2398	1.2047	1.1699	1.1646	1.2194	1.4336	1.5739
13,500	1.2427	1.2010	1.1722	1.1757	1.2661	1.4930	1.5848
14,000	1.2428	1.1989	1.1760	1.1907	1.3229	1.5332	1.5902
14,500	1.2415	1.1982	1.1814	1.2111	1.3833	1.5581	1.5930
15,000	1.2397	1.1989	1.1882	1.2378	1.4390	1.5730	1.5944

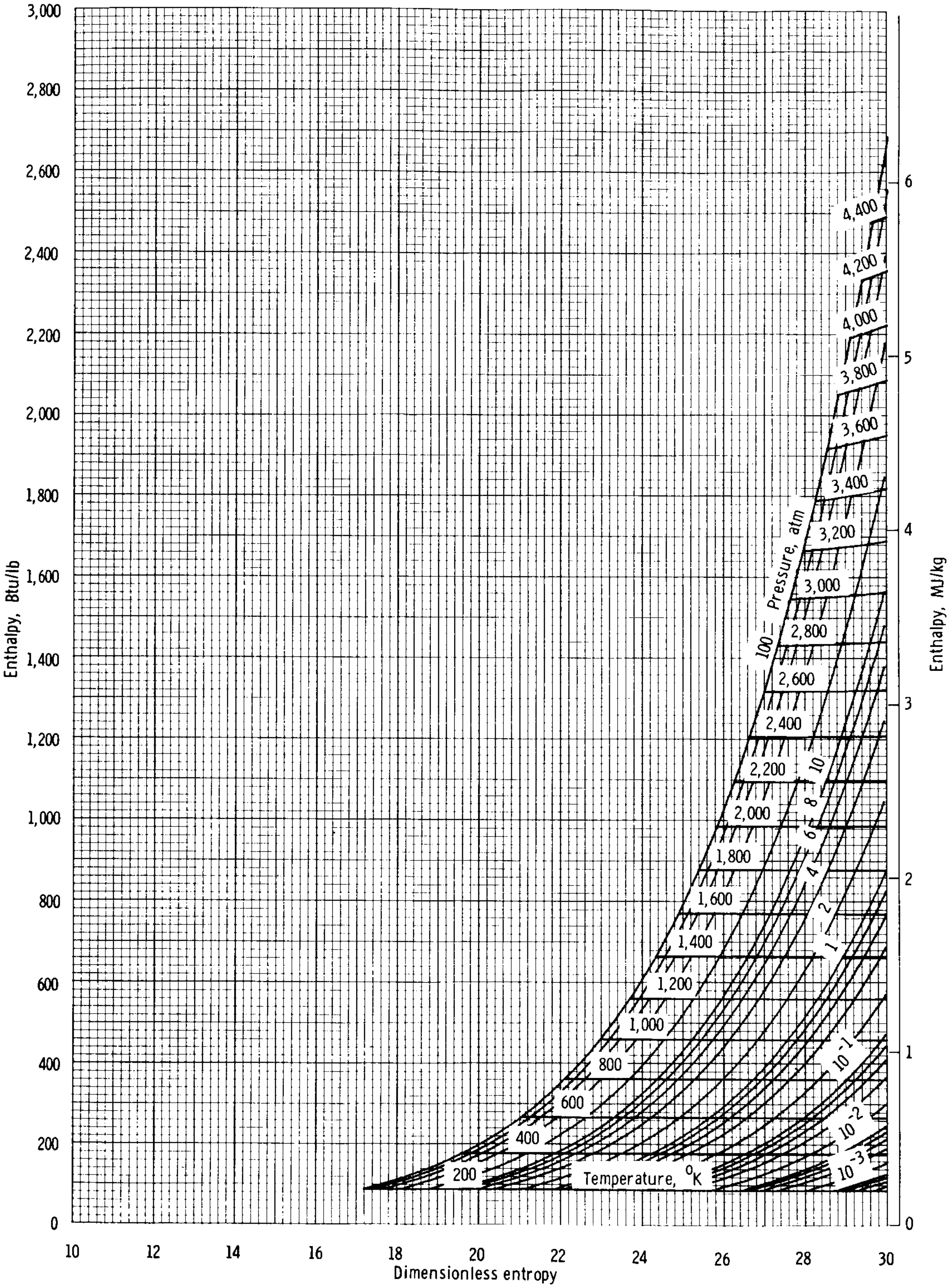


Chart 1

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2.

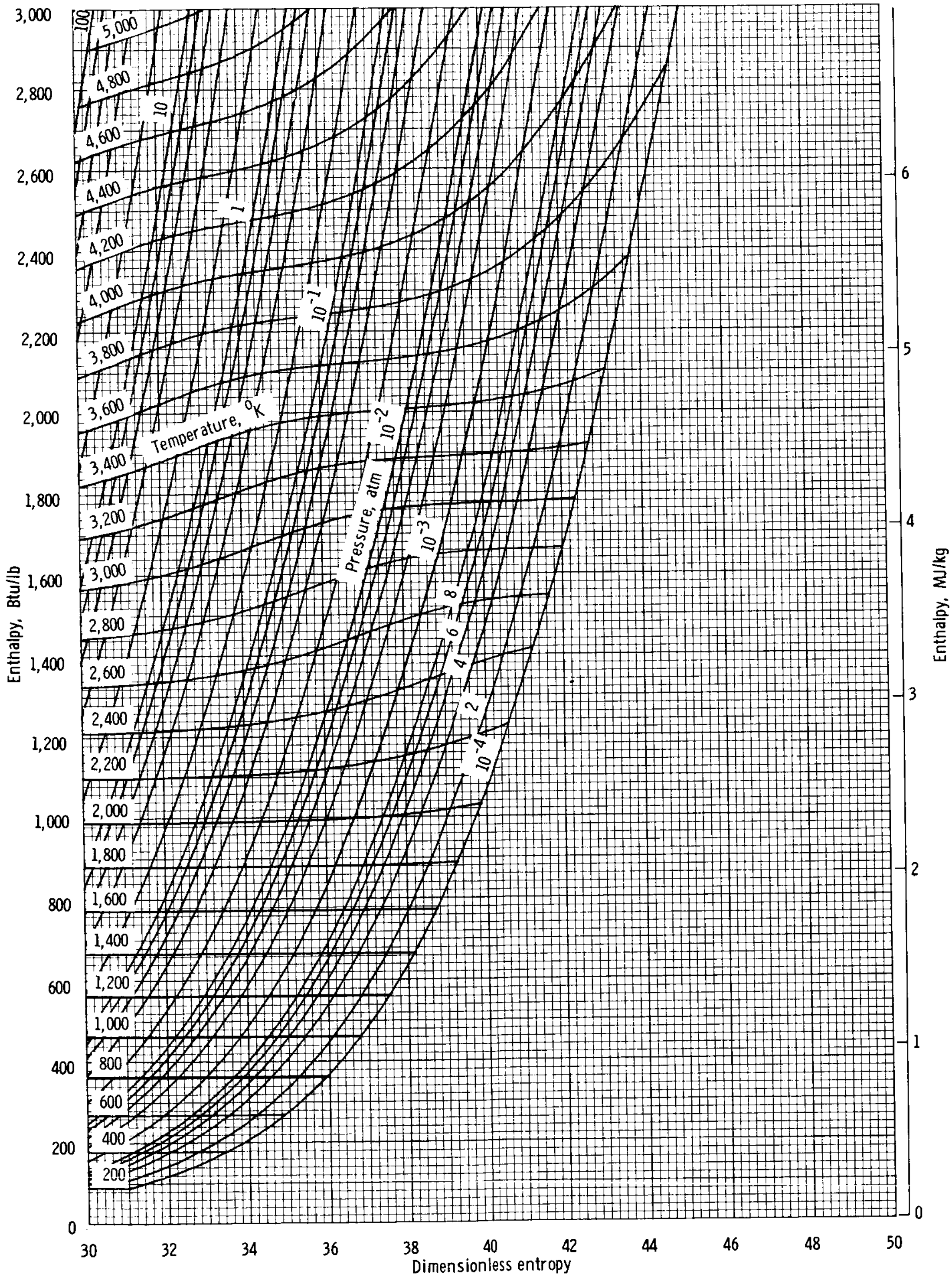


Chart 2

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

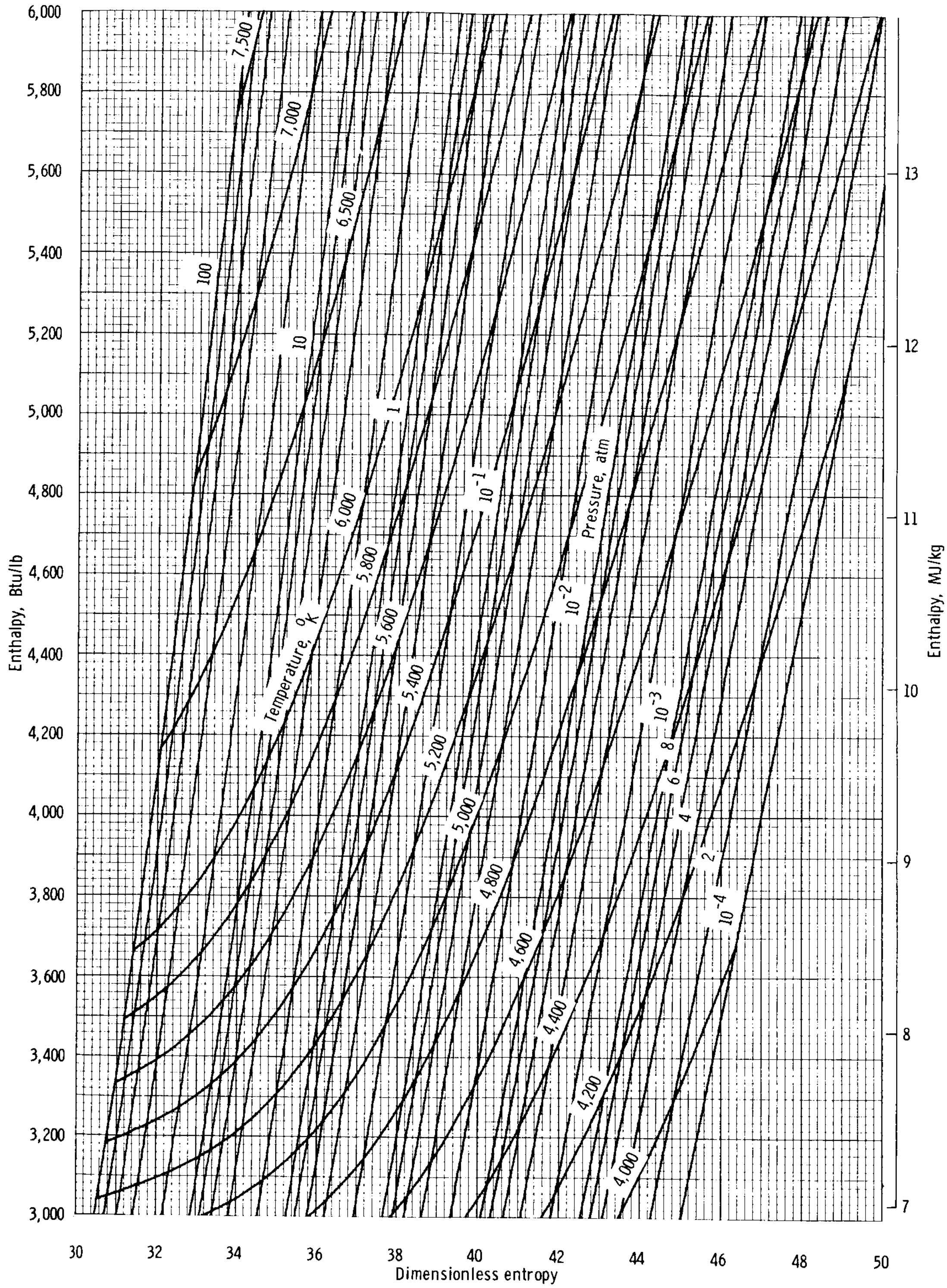


Chart 3

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

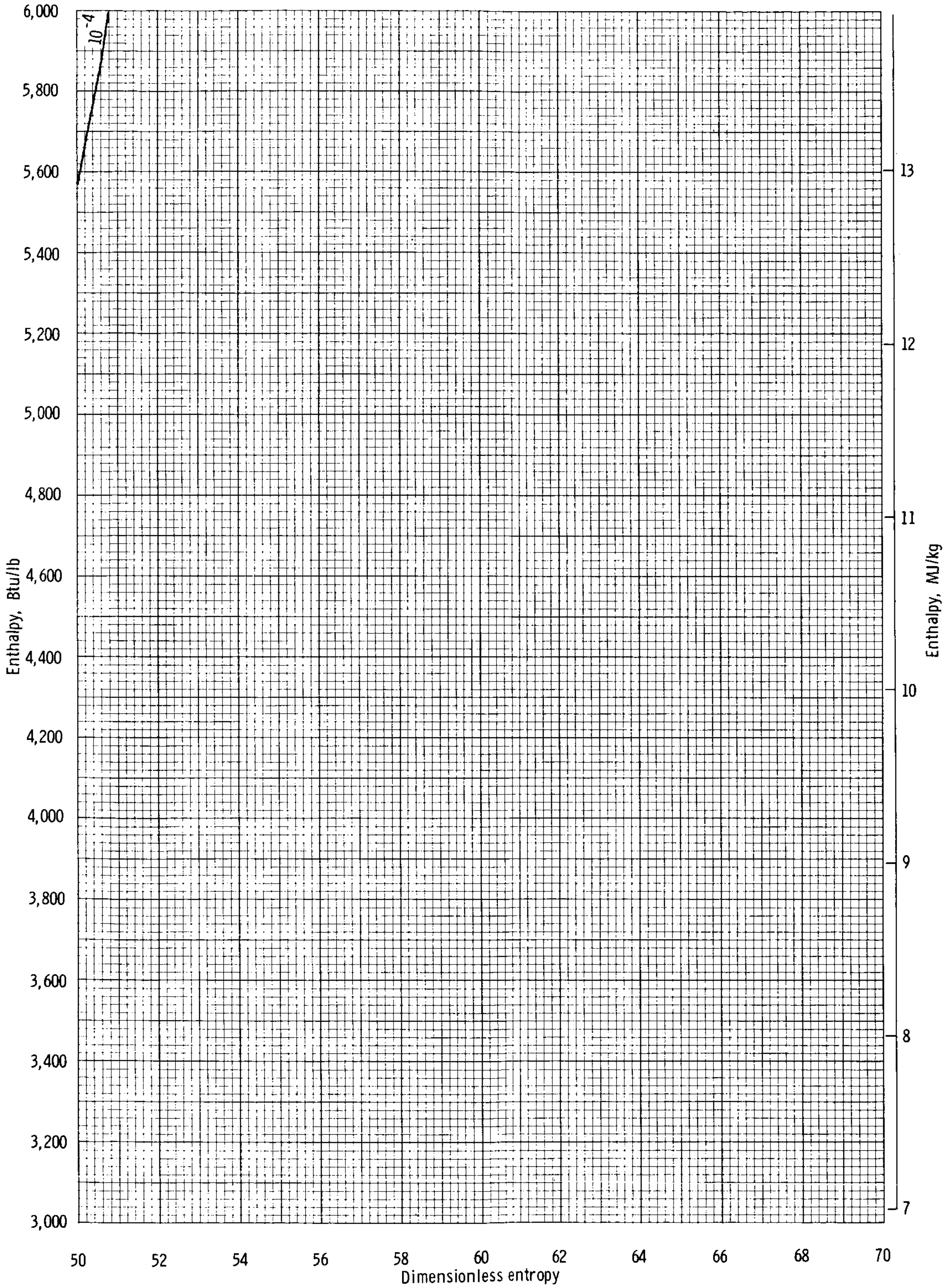


Chart 4

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

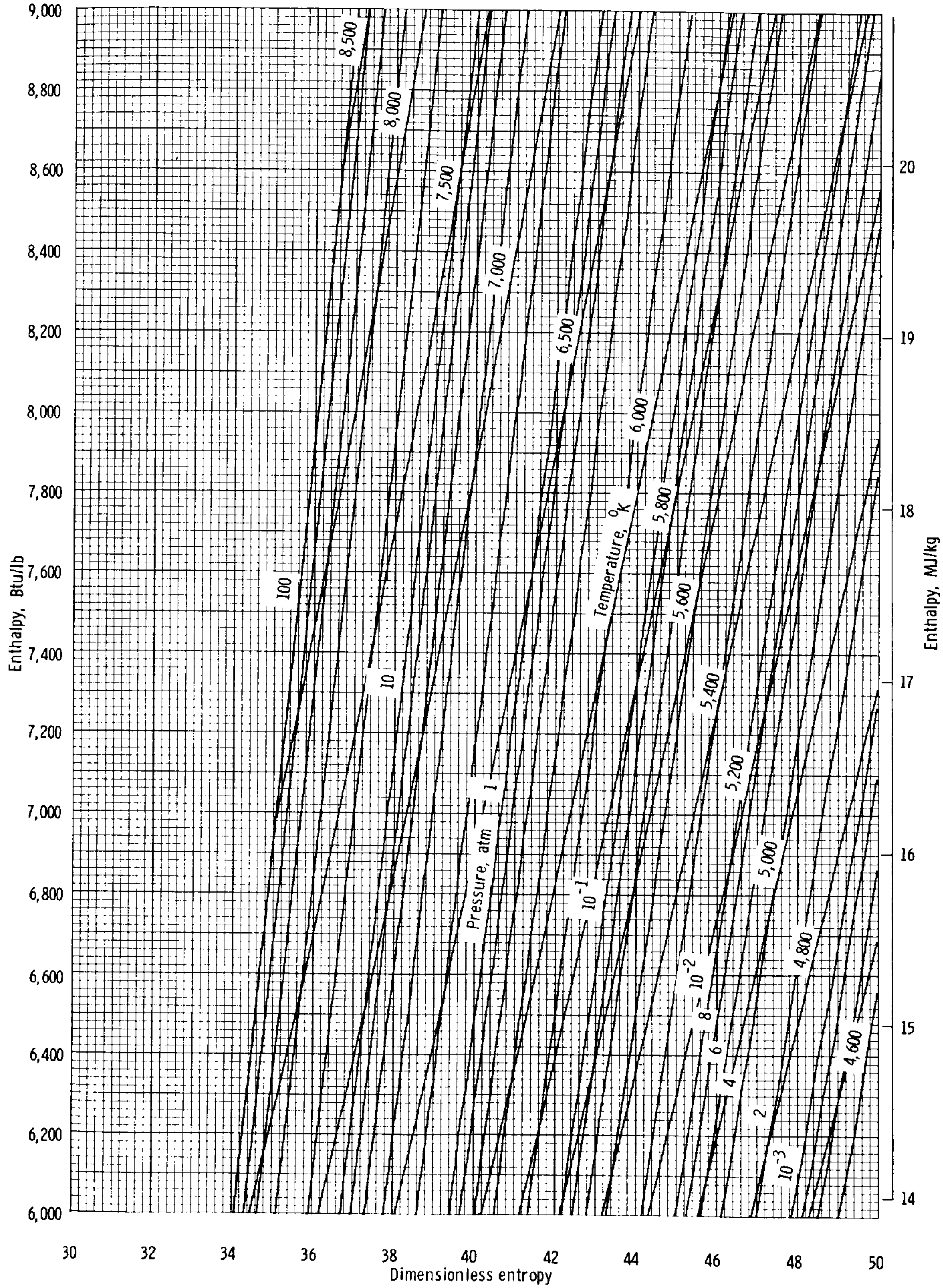


Chart 5

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

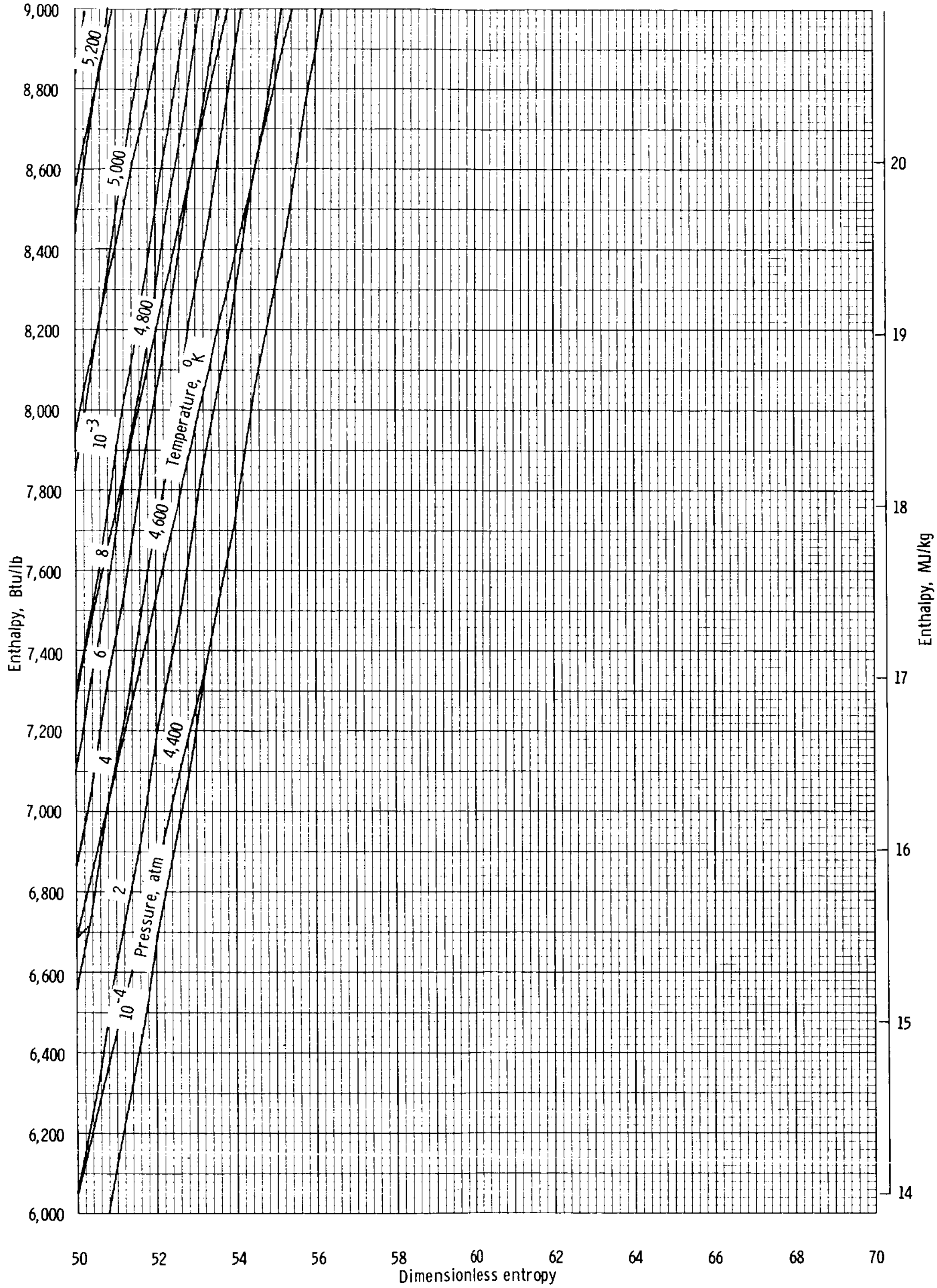


Chart 6

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

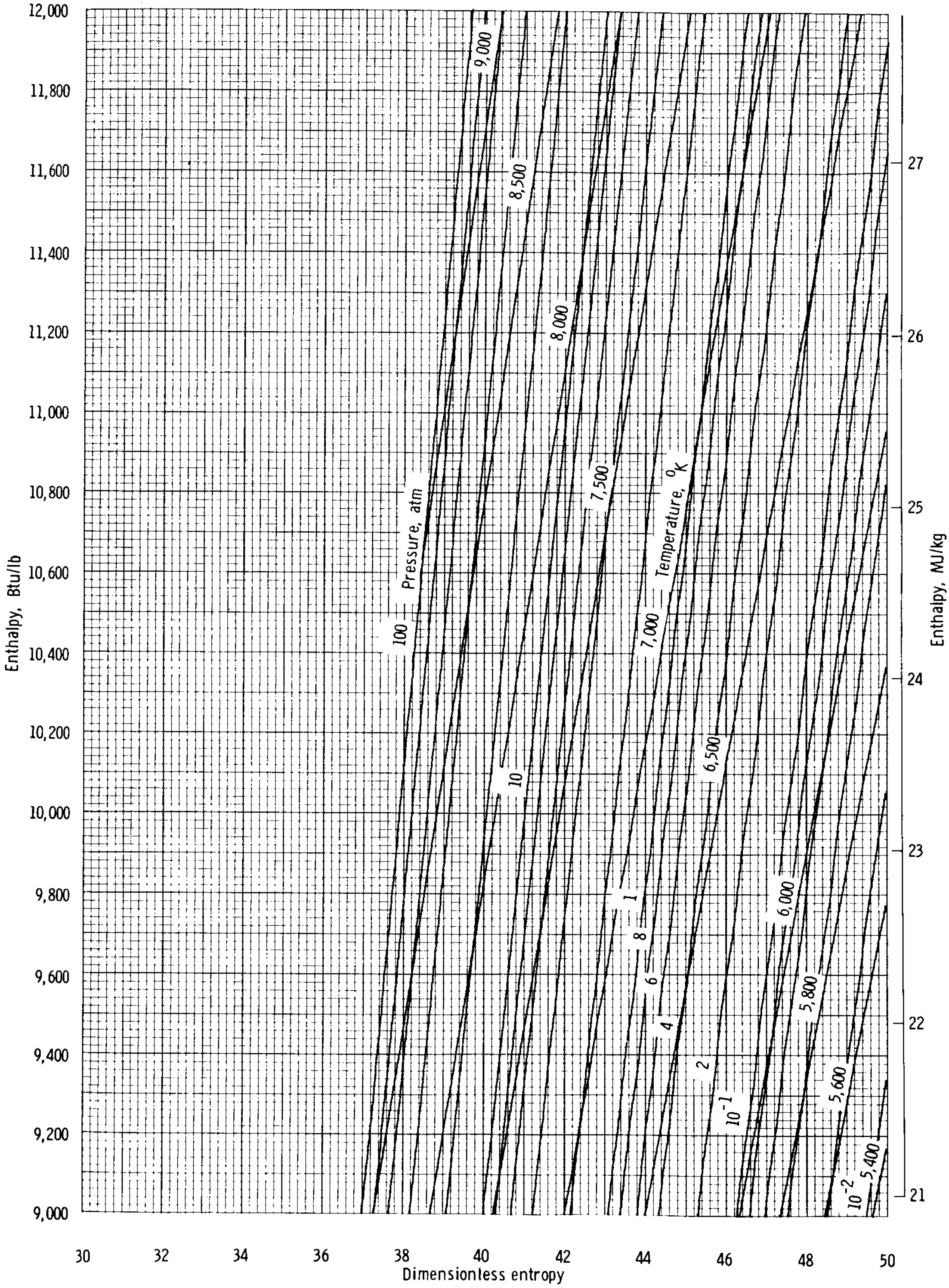


Chart 7

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

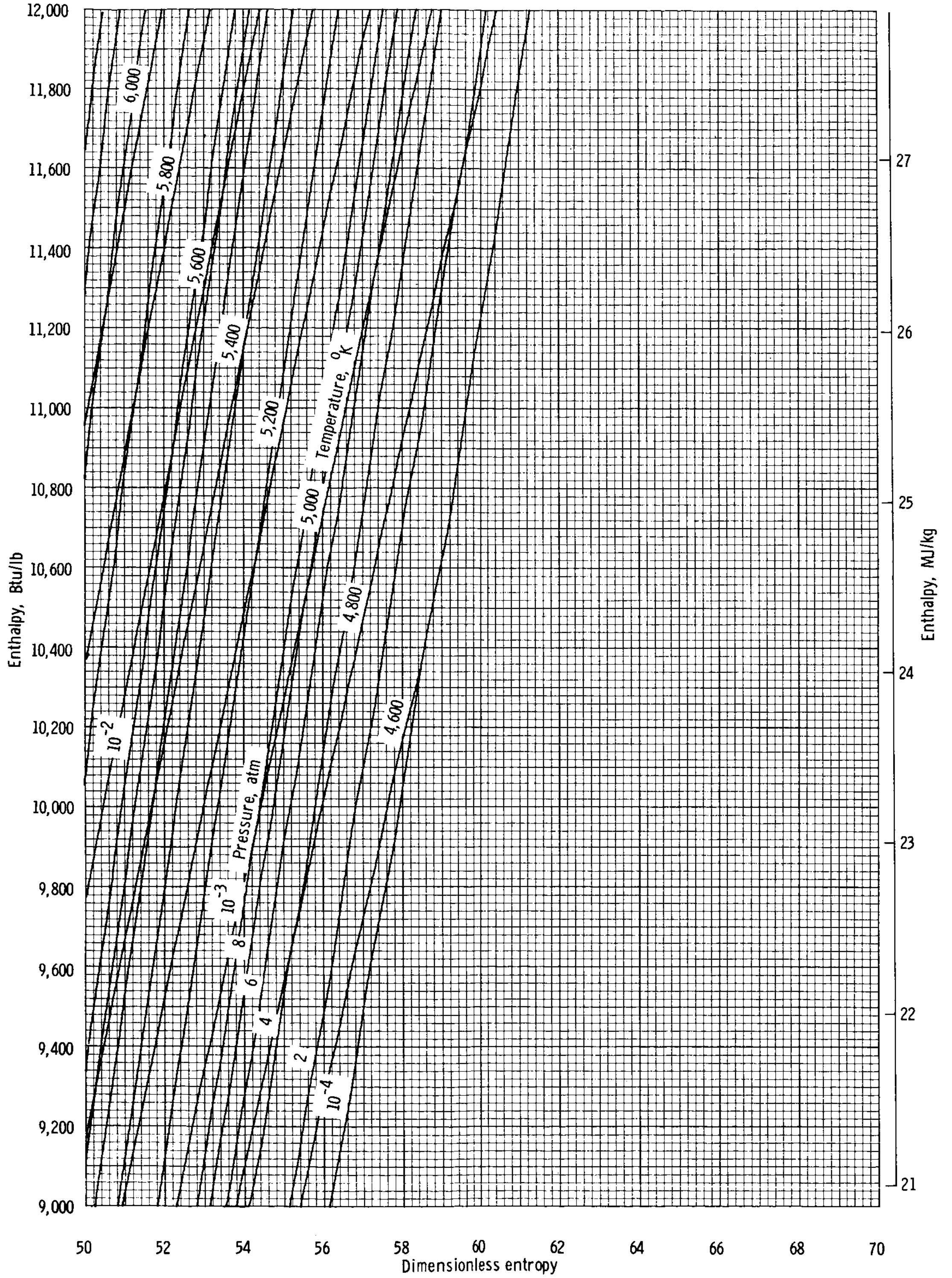


Chart 8

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

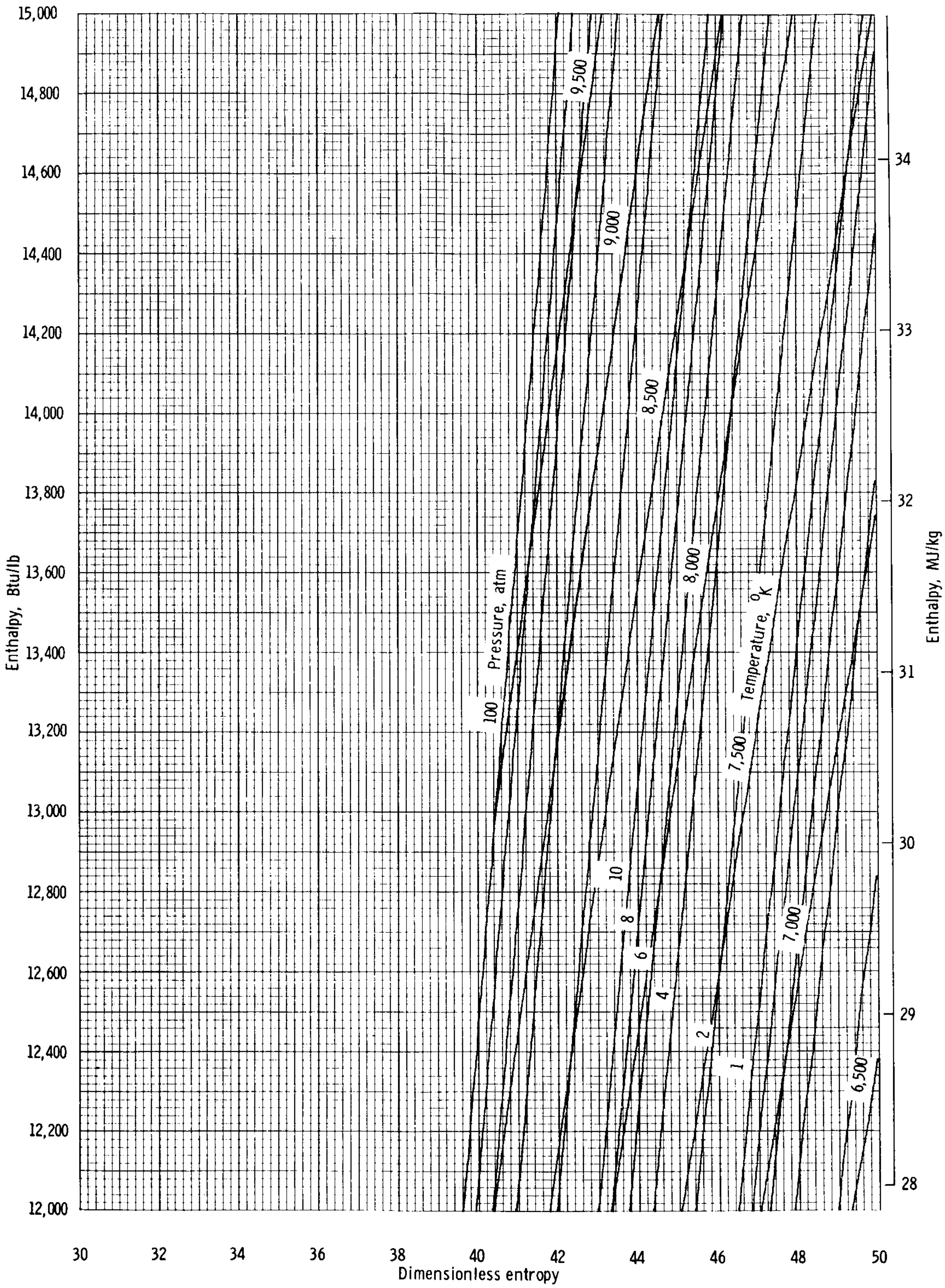


Chart 9

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

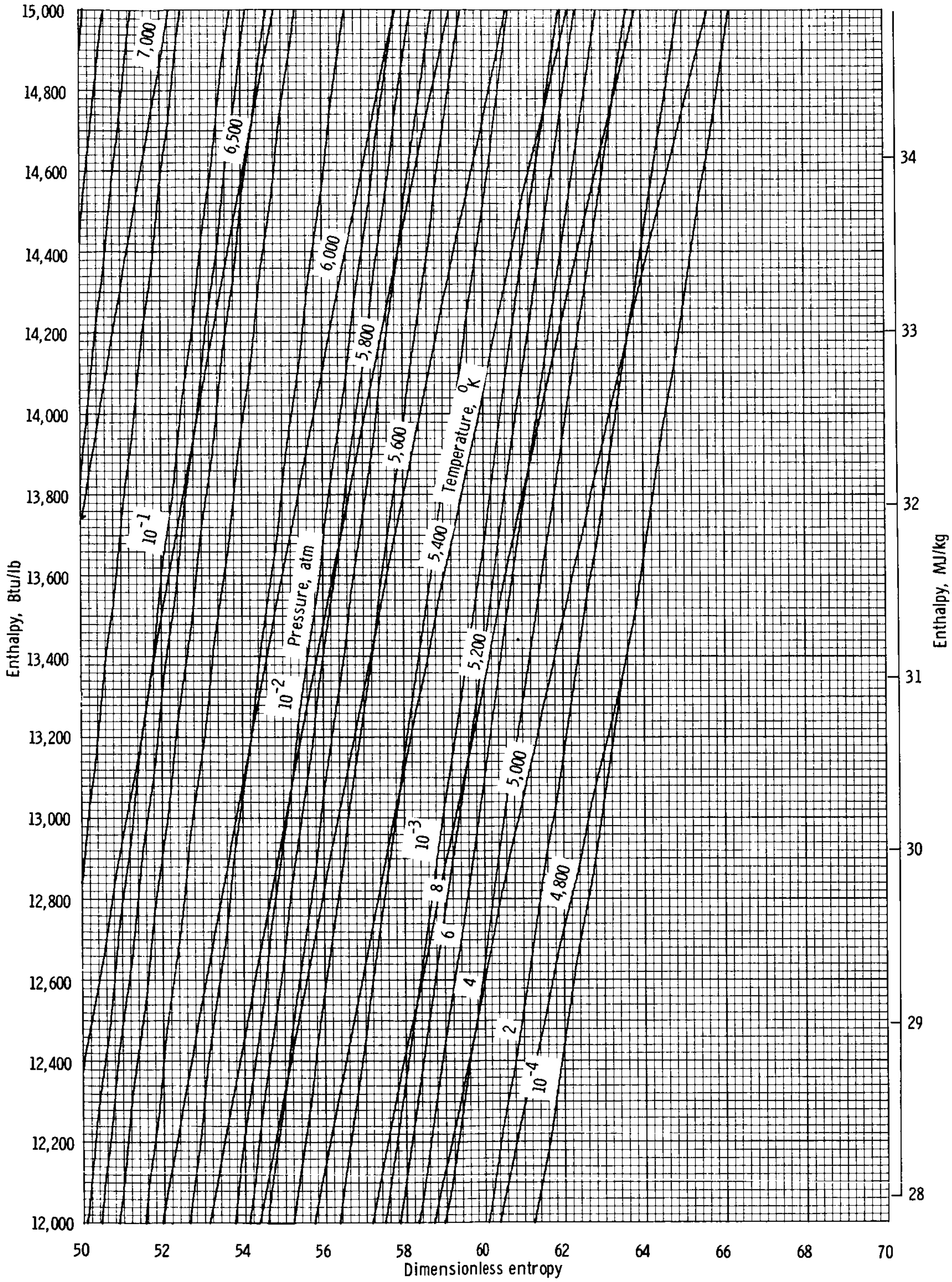


Chart 10

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

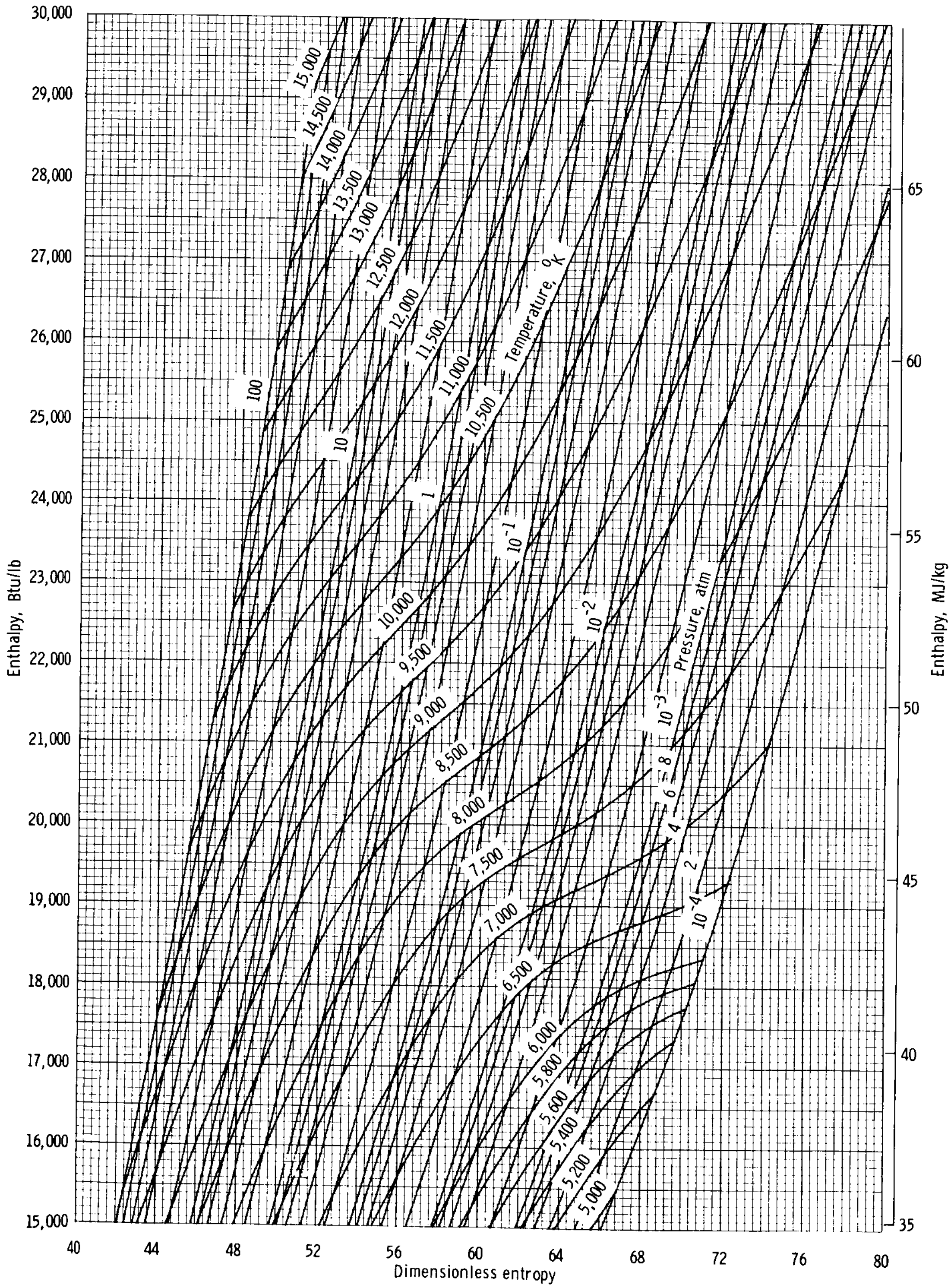


Chart 11

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

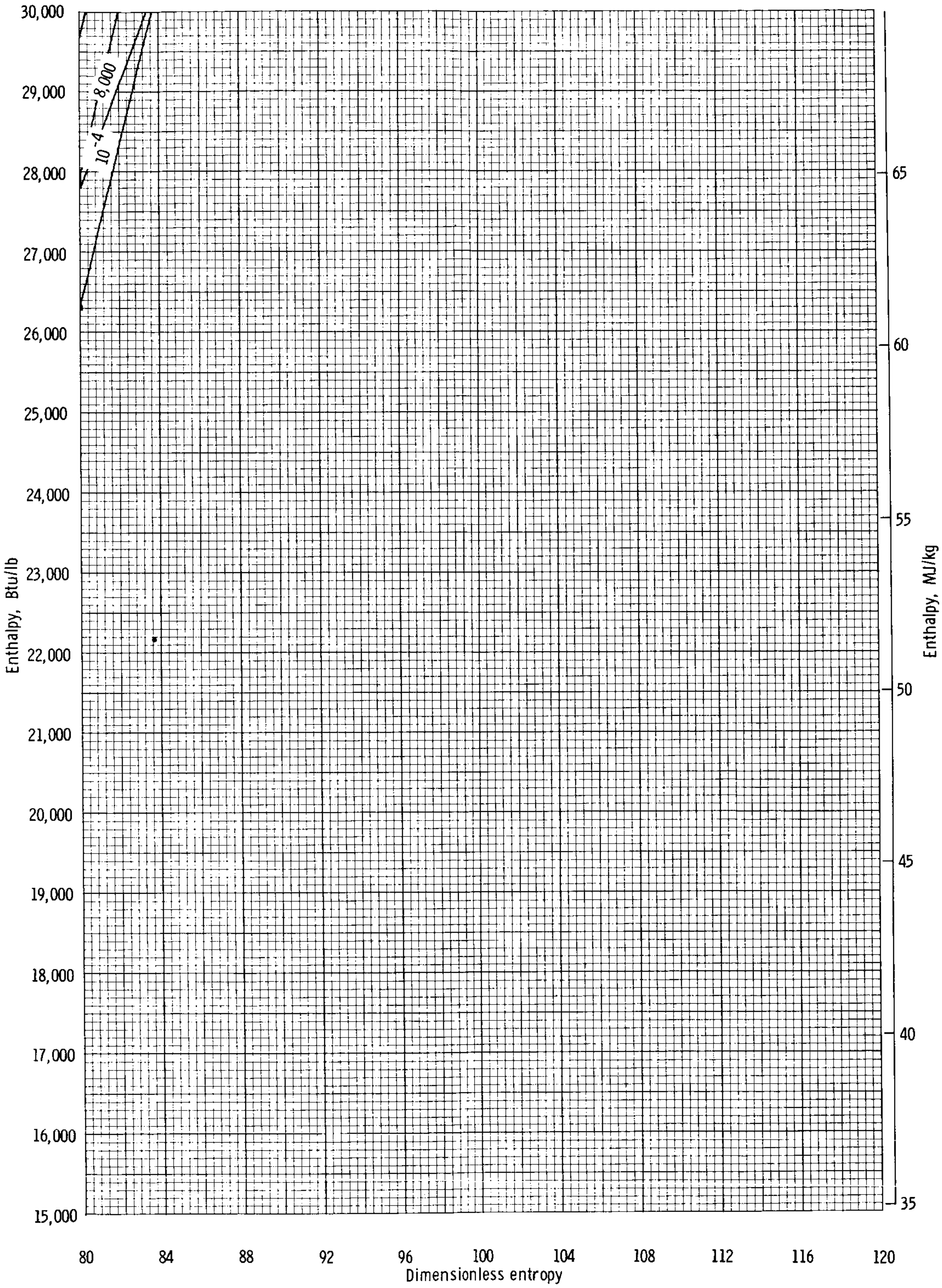


Chart 12

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

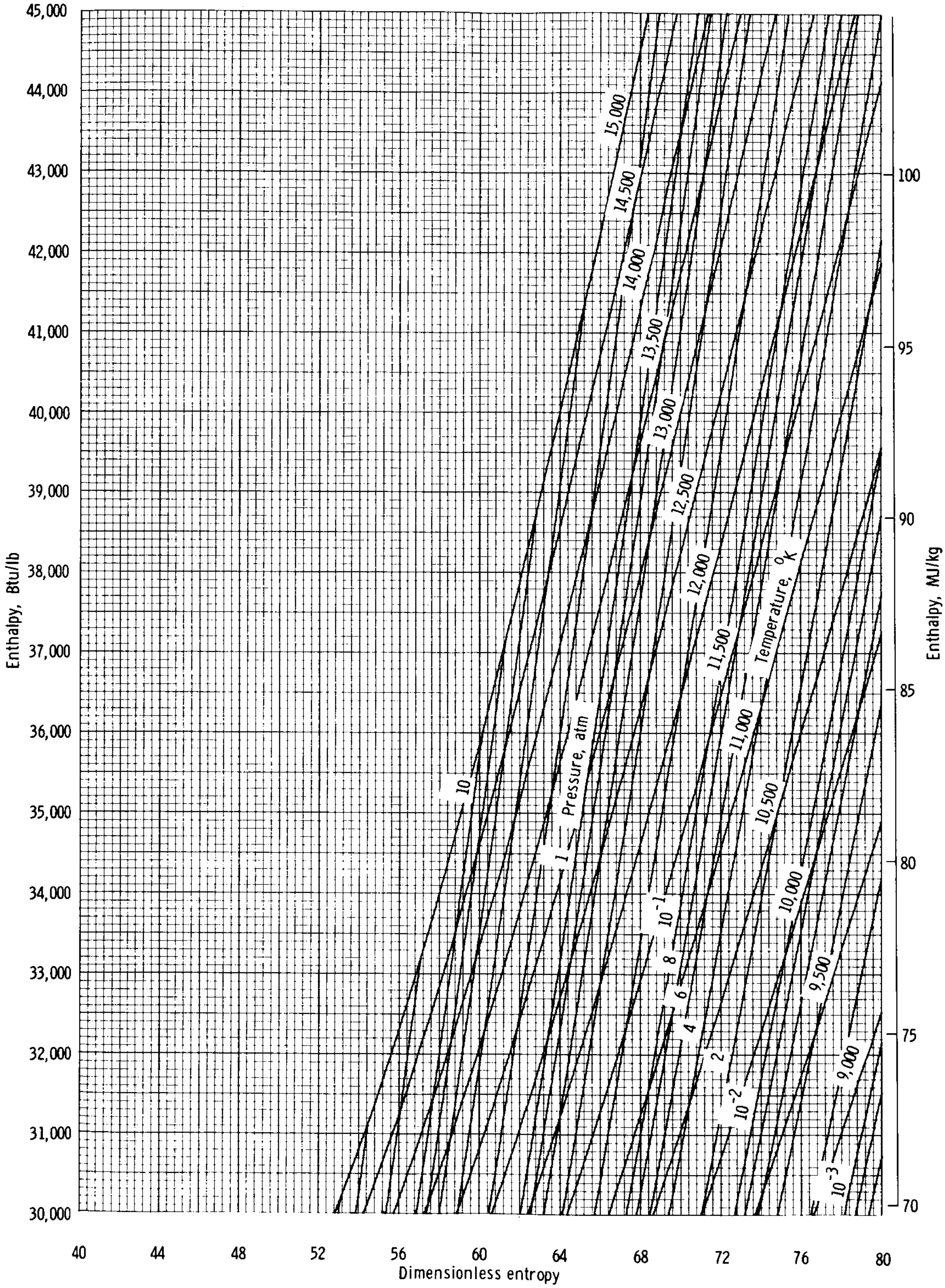


Chart 13

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

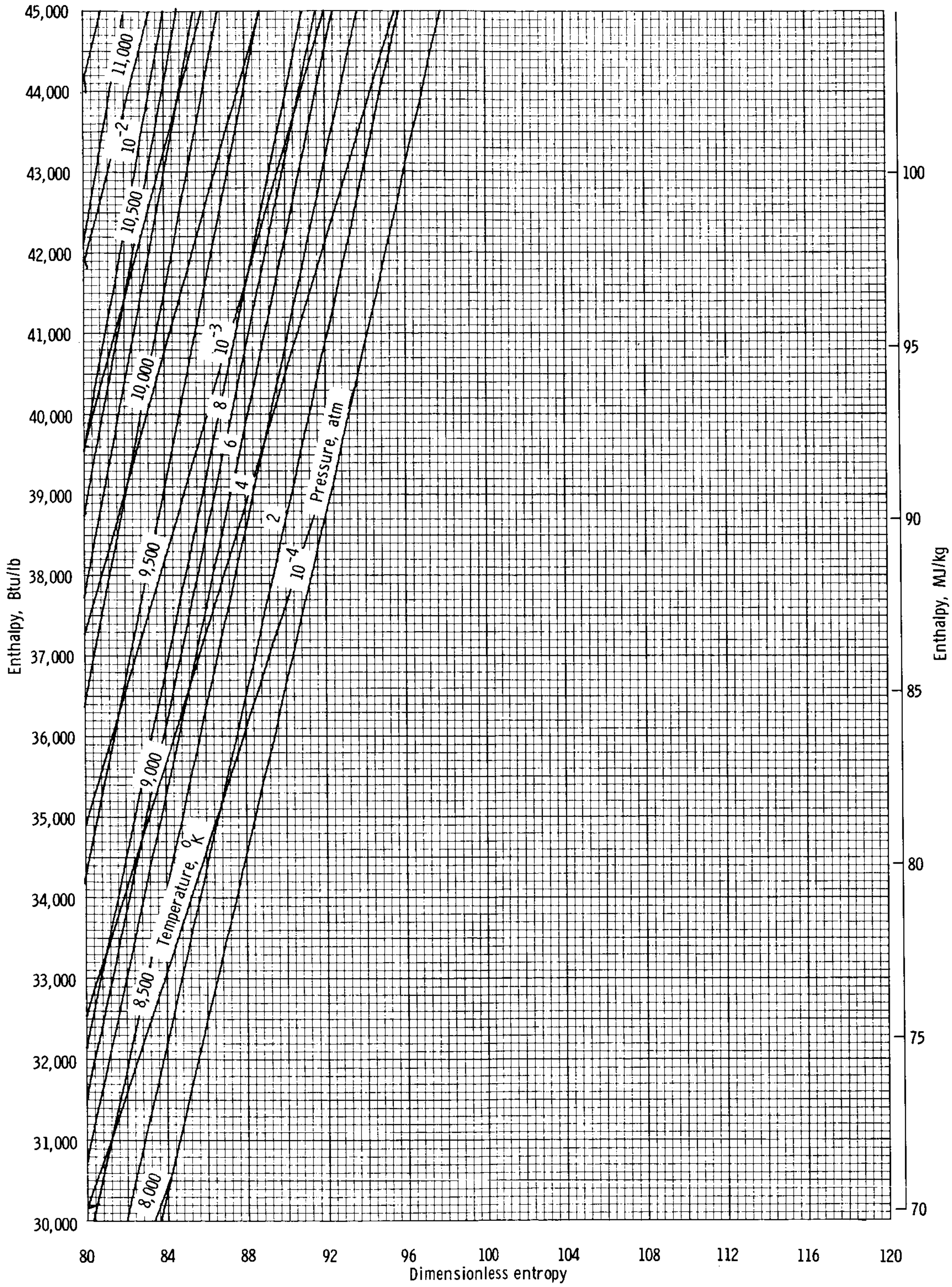


Chart 14

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

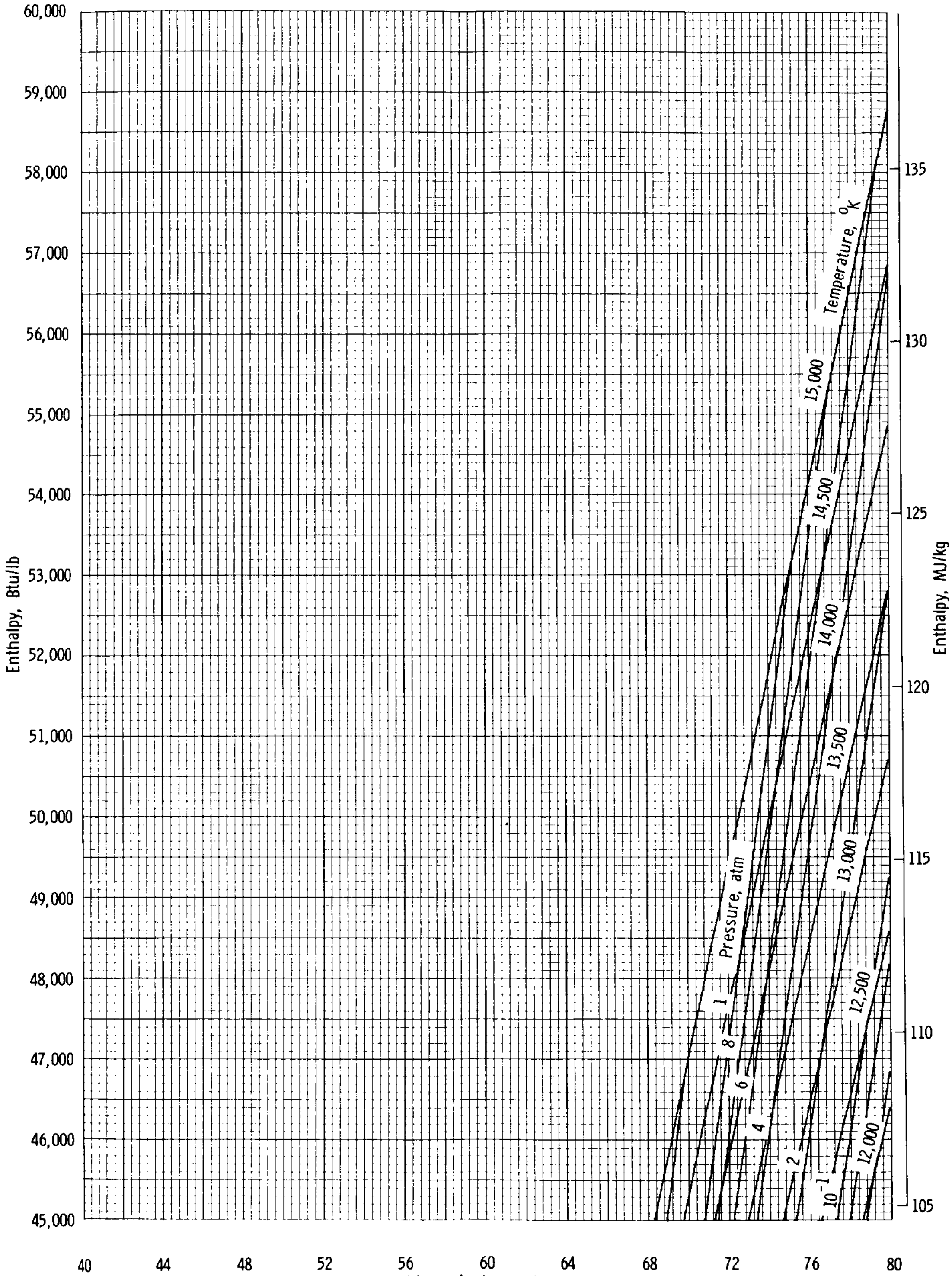


Chart 15

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

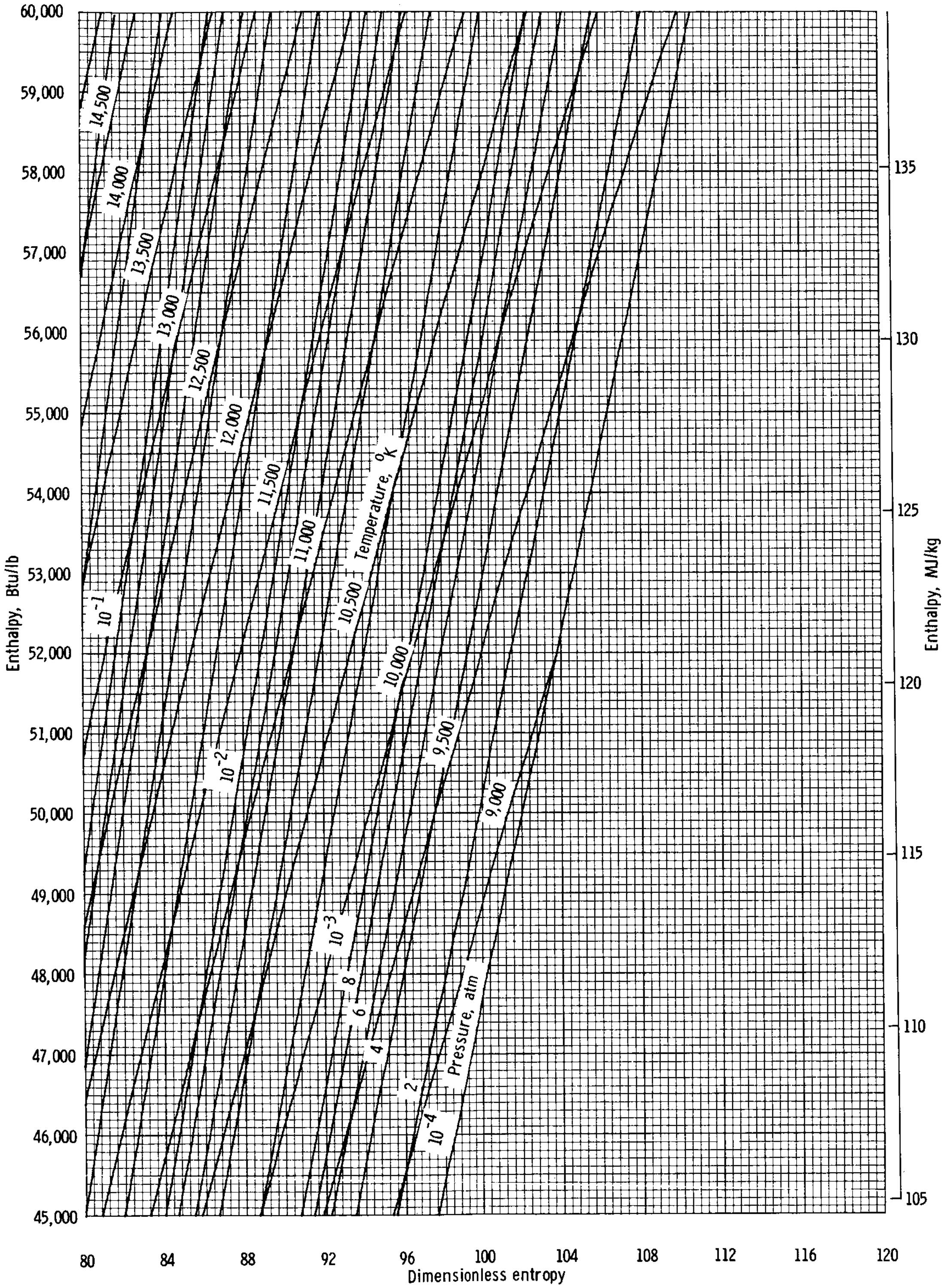


Chart 16

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

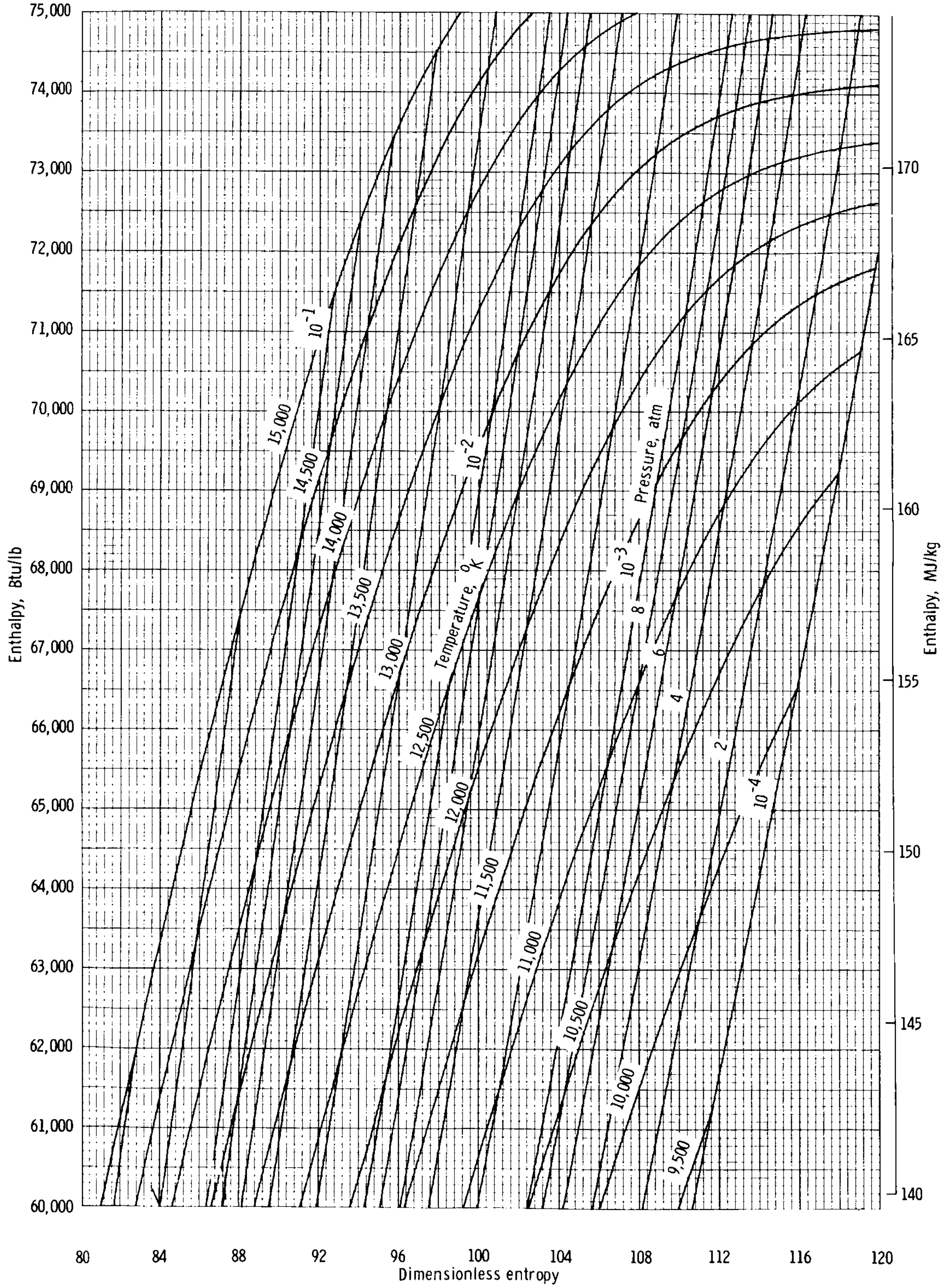


Chart 17

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

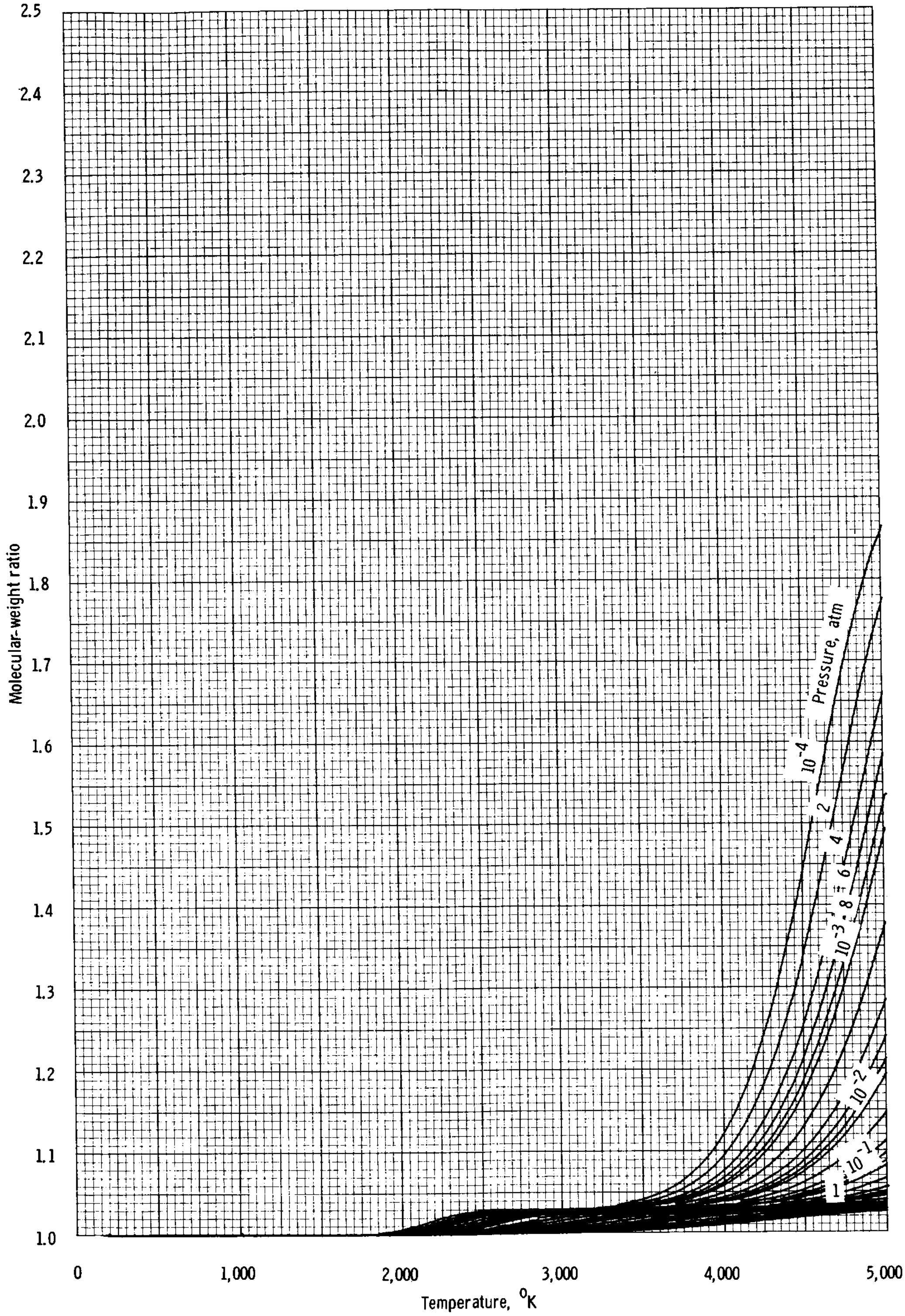


Chart 18

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

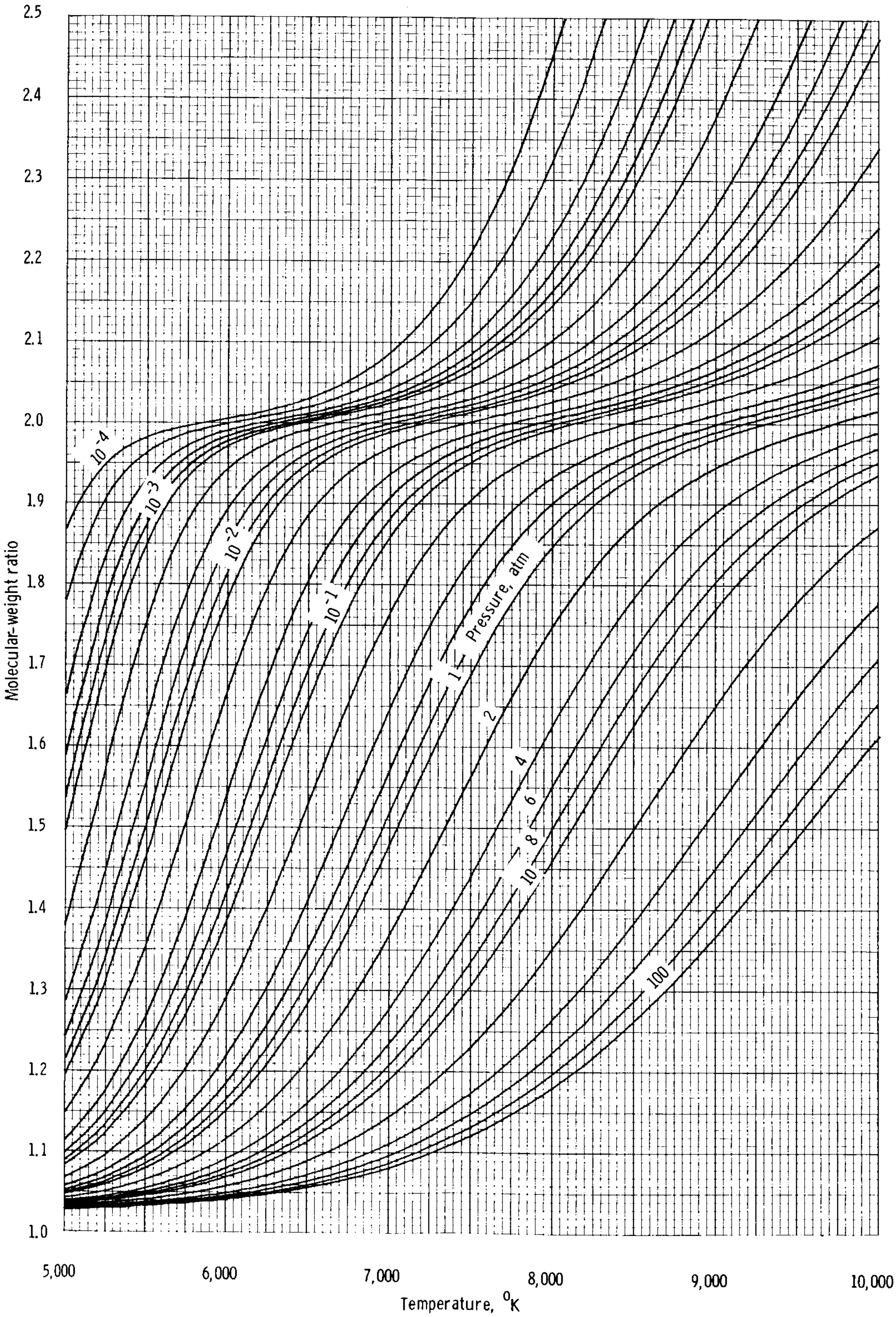


Chart 19

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

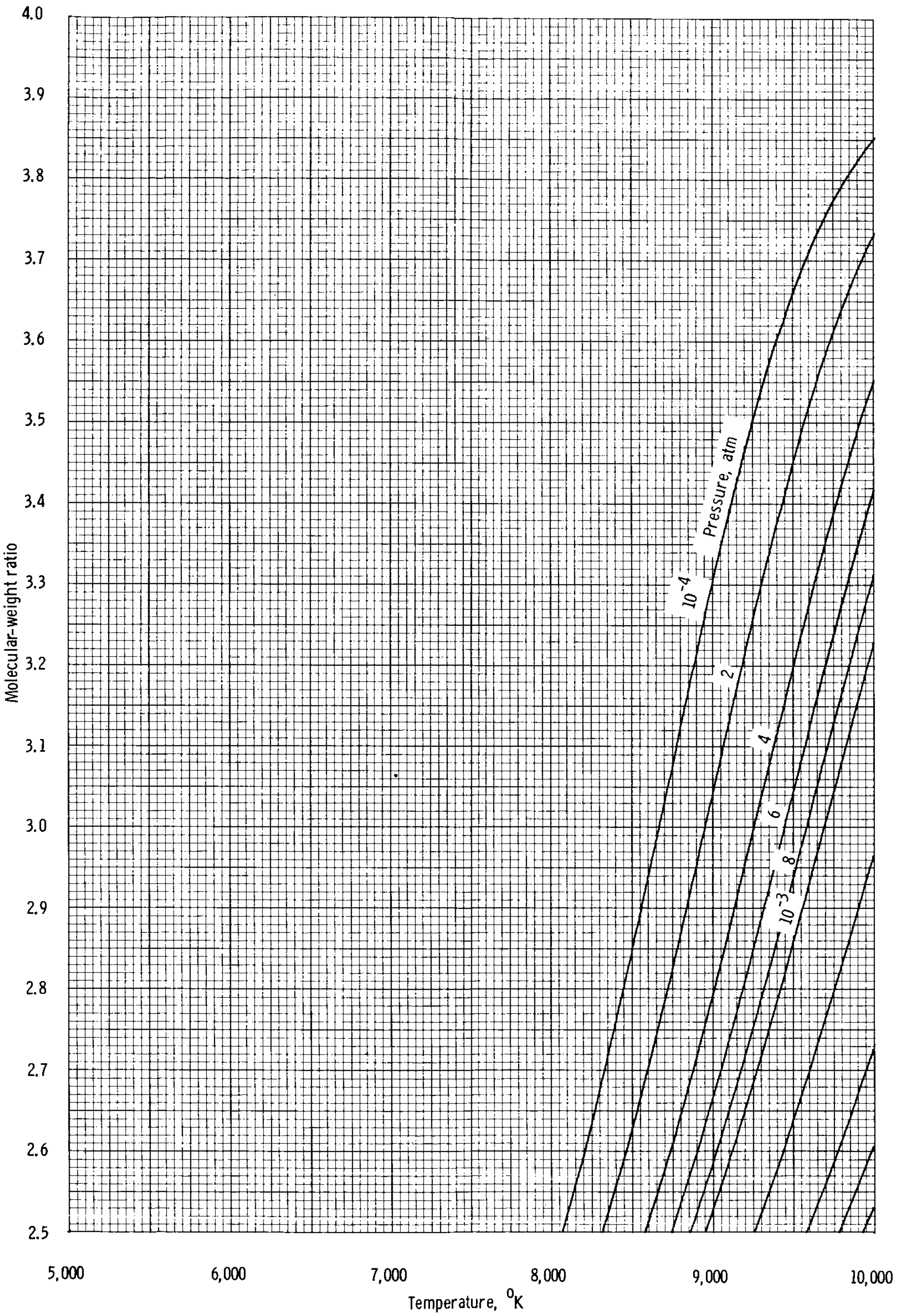


Chart 20

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Continued.

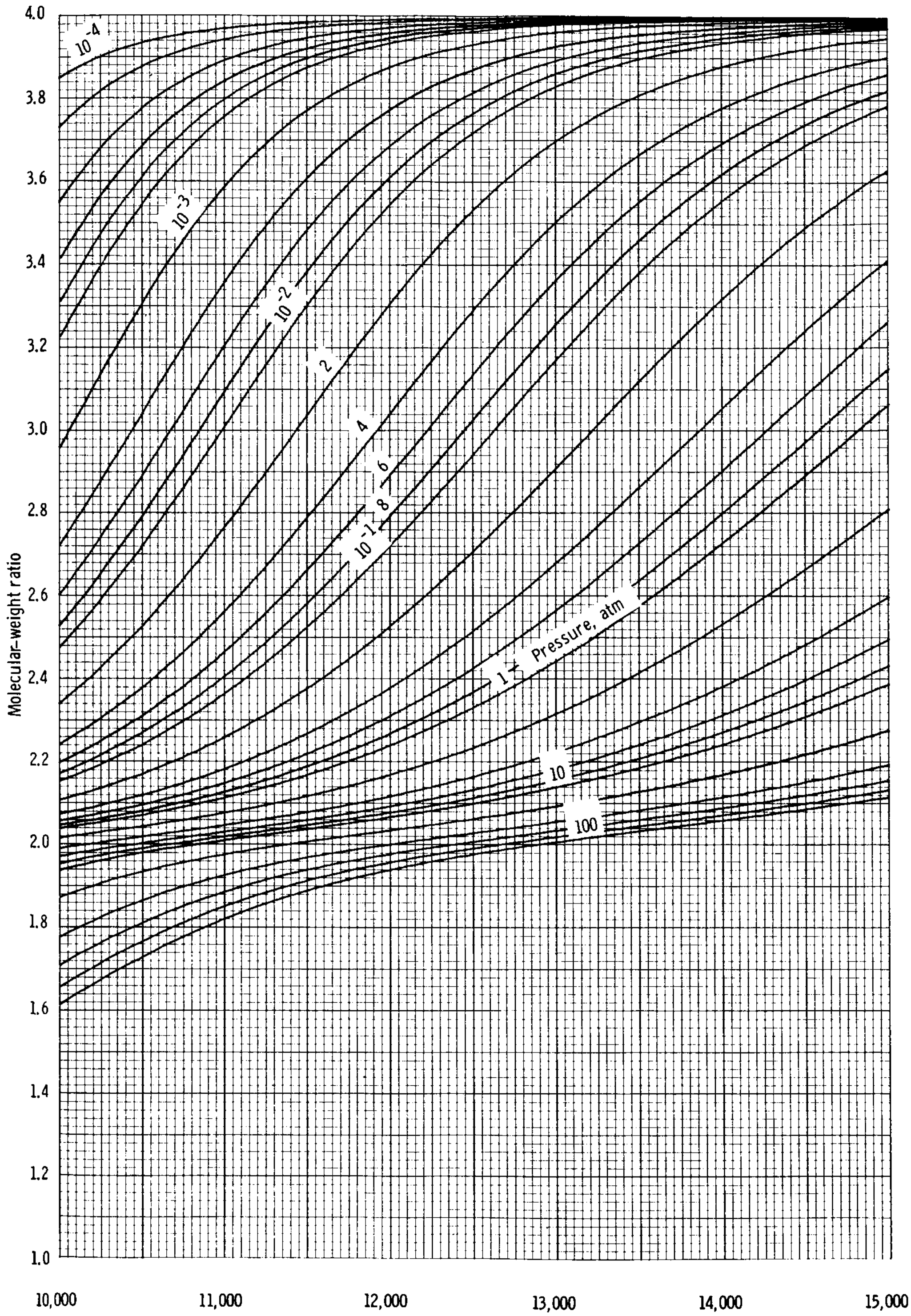


Chart 21

Figure 3.- Thermodynamic charts for 97 percent N_2 and 3 percent O_2. Concluded.

TABLE III.- THERMODYNAMIC PROPERTIES OF 97 PERCENT N_2 AND 3 PERCENT O_2

(a) Ratio of specific heats γ

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3972	1.3972	1.3972	1.3972	1.3972	1.3972	1.3972
600	1.3817	1.3817	1.3817	1.3817	1.3817	1.3817	1.3817
800	1.3604	1.3604	1.3604	1.3604	1.3604	1.3604	1.3604
1,000	1.3422	1.3422	1.3422	1.3422	1.3422	1.3422	1.3422
1,200	1.3288	1.3288	1.3288	1.3288	1.3288	1.3288	1.3288
1,400	1.3192	1.3192	1.3192	1.3192	1.3191	1.3190	1.3185
1,600	1.3123	1.3122	1.3122	1.3120	1.3115	1.3098	1.3047
1,800	1.3071	1.3070	1.3067	1.3057	1.3025	1.2931	1.2687
2,000	1.3031	1.3027	1.3014	1.2973	1.2855	1.2569	1.2102
2,200	1.2997	1.2984	1.2944	1.2829	1.2555	1.2132	1.1878
2,400	1.2965	1.2932	1.2839	1.2610	1.2237	1.2004	1.2378
2,600	1.2929	1.2863	1.2693	1.2380	1.2122	1.2371	1.2888
2,800	1.2886	1.2774	1.2534	1.2256	1.2325	1.2808	1.2922
3,000	1.2835	1.2674	1.2415	1.2314	1.2681	1.2882	1.2713
3,200	1.2778	1.2582	1.2384	1.2532	1.2831	1.2724	1.2291
3,400	1.2721	1.2522	1.2455	1.2729	1.2754	1.2396	1.1777
3,600	1.2670	1.2508	1.2590	1.2762	1.2528	1.1973	1.1393
3,800	1.2634	1.2541	1.2696	1.2648	1.2206	1.1602	1.1250
4,000	1.2618	1.2603	1.2703	1.2436	1.1872	1.1386	1.1343
4,200	1.2621	1.2659	1.2611	1.2175	1.1612	1.1352	1.1635
4,400	1.2637	1.2671	1.2452	1.1922	1.1473	1.1487	1.2011
4,600	1.2657	1.2625	1.2258	1.1723	1.1464	1.1758	1.2201
4,800	1.2666	1.2529	1.2066	1.1606	1.1576	1.2081	1.2026
5,000	1.2654	1.2401	1.1902	1.1579	1.1790	1.2289	1.1756
5,200	1.2614	1.2263	1.1786	1.1639	1.2061	1.2240	1.1745
5,400	1.2549	1.2131	1.1727	1.1777	1.2307	1.2016	1.2062
5,600	1.2466	1.2019	1.1728	1.1976	1.2422	1.1859	1.2497
5,800	1.2376	1.1937	1.1786	1.2204	1.2355	1.1909	1.2696
6,000	1.2286	1.1891	1.1896	1.2412	1.2182	1.2146	1.2561
6,500	1.2113	1.1938	1.2323	1.2517	1.2048	1.2504	1.1848
7,000	1.2060	1.2190	1.2687	1.2212	1.2385	1.2045	1.1522
7,500	1.2143	1.2553	1.2650	1.2225	1.2269	1.1695	1.1620
8,000	1.2346	1.2846	1.2409	1.2359	1.1953	1.1654	1.2009
8,500	1.2624	1.2896	1.2335	1.2250	1.1792	1.1868	1.2412
9,000	1.2902	1.2738	1.2381	1.2063	1.1826	1.2235	1.2414
9,500	1.3087	1.2572	1.2358	1.1963	1.2023	1.2559	1.2127
10,000	1.3122	1.2509	1.2266	1.1984	1.2325	1.2605	1.2114
10,500	1.3031	1.2506	1.2189	1.2115	1.2630	1.2409	1.2614
11,000	1.2900	1.2496	1.2172	1.2331	1.2803	1.2287	1.3509
11,500	1.2799	1.2465	1.2224	1.2592	1.2778	1.2462	1.4436
12,000	1.2752	1.2439	1.2341	1.2839	1.2641	1.2962	1.5108
12,500	1.2741	1.2437	1.2510	1.3008	1.2561	1.3665	1.5500
13,000	1.2744	1.2470	1.2714	1.3060	1.2656	1.4372	1.5706
13,500	1.2749	1.2540	1.2928	1.3012	1.2951	1.4934	1.5810
14,000	1.2757	1.2645	1.3124	1.2932	1.3407	1.5317	1.5862
14,500	1.2775	1.2778	1.3274	1.2897	1.3937	1.5555	1.5889
15,000	1.2806	1.2934	1.3360	1.2958	1.4445	1.5698	1.5902

TABLE III.- THERMODYNAMIC PROPERTIES OF 97 PERCENT N_2 AND 3 PERCENT O_2 - Concluded

(b) Dimensionless speed-of-sound parameter $a^2\rho/p$

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3972	1.3972	1.3972	1.3972	1.3972	1.3972	1.3972
600	1.3817	1.3817	1.3817	1.3817	1.3817	1.3817	1.3817
800	1.3604	1.3604	1.3604	1.3604	1.3604	1.3604	1.3604
1,000	1.3422	1.3422	1.3422	1.3422	1.3422	1.3422	1.3422
1,200	1.3288	1.3288	1.3288	1.3288	1.3288	1.3288	1.3288
1,400	1.3192	1.3192	1.3192	1.3192	1.3191	1.3190	1.3185
1,600	1.3123	1.3122	1.3122	1.3120	1.3115	1.3098	1.3046
1,800	1.3071	1.3070	1.3067	1.3056	1.3024	1.2929	1.2680
2,000	1.3031	1.3027	1.3013	1.2971	1.2851	1.2557	1.2071
2,200	1.2997	1.2984	1.2942	1.2824	1.2541	1.2095	1.1818
2,400	1.2964	1.2931	1.2834	1.2595	1.2200	1.1943	1.2347
2,600	1.2927	1.2859	1.2680	1.2346	1.2062	1.2334	1.2881
2,800	1.2883	1.2764	1.2507	1.2200	1.2276	1.2796	1.2920
3,000	1.2828	1.2655	1.2370	1.2254	1.2659	1.2878	1.2709
3,200	1.2766	1.2550	1.2324	1.2490	1.2822	1.2719	1.2277
3,400	1.2700	1.2474	1.2395	1.2708	1.2748	1.2382	1.1737
3,600	1.2640	1.2448	1.2544	1.2750	1.2516	1.1941	1.1296
3,800	1.2592	1.2477	1.2667	1.2637	1.2181	1.1528	1.1034
4,000	1.2564	1.2546	1.2684	1.2417	1.1820	1.1234	1.0908
4,200	1.2558	1.2614	1.2593	1.2141	1.1513	1.1062	1.0864
4,400	1.2572	1.2637	1.2427	1.1860	1.1292	1.0976	1.0866
4,600	1.2594	1.2596	1.2220	1.1616	1.1154	1.0945	1.0903
4,800	1.2609	1.2499	1.2004	1.1430	1.1078	1.0949	1.0980
5,000	1.2604	1.2363	1.1805	1.1301	1.1045	1.0981	1.1132
5,200	1.2568	1.2209	1.1638	1.1219	1.1042	1.1040	1.1427
5,400	1.2503	1.2054	1.1509	1.1174	1.1061	1.1143	1.1904
5,600	1.2415	1.1909	1.1414	1.1156	1.1099	1.1319	1.2413
5,800	1.2314	1.1784	1.1351	1.1158	1.1160	1.1600	1.2642
6,000	1.2208	1.1680	1.1312	1.1175	1.1253	1.1969	1.2513
6,500	1.1961	1.1513	1.1291	1.1283	1.1711	1.2436	1.1753
7,000	1.1782	1.1449	1.1343	1.1523	1.2261	1.1955	1.1284
7,500	1.1676	1.1451	1.1459	1.1926	1.2177	1.1506	1.1094
8,000	1.1628	1.1498	1.1657	1.2210	1.1811	1.1272	1.1042
8,500	1.1624	1.1584	1.1930	1.2124	1.1535	1.1175	1.1064
9,000	1.1650	1.1712	1.2153	1.1892	1.1381	1.1158	1.1148
9,500	1.1702	1.1884	1.2188	1.1696	1.1312	1.1190	1.1330
10,000	1.1777	1.2070	1.2085	1.1568	1.1298	1.1269	1.1714
10,500	1.1874	1.2211	1.1950	1.1500	1.1323	1.1414	1.2424
11,000	1.1994	1.2261	1.1838	1.1474	1.1381	1.1673	1.3416
11,500	1.2127	1.2236	1.1761	1.1481	1.1476	1.2113	1.4388
12,000	1.2256	1.2176	1.1716	1.1513	1.1623	1.2764	1.5083
12,500	1.2359	1.2111	1.1698	1.1567	1.1850	1.3551	1.5486
13,000	1.2423	1.2056	1.1702	1.1646	1.2186	1.4305	1.5698
13,500	1.2449	1.2018	1.1724	1.1755	1.2646	1.4894	1.5805
14,000	1.2447	1.1995	1.1761	1.1904	1.3208	1.5292	1.5860
14,500	1.2430	1.1987	1.1814	1.2104	1.3805	1.5540	1.5887
15,000	1.2409	1.1992	1.1881	1.2368	1.4357	1.5688	1.5901

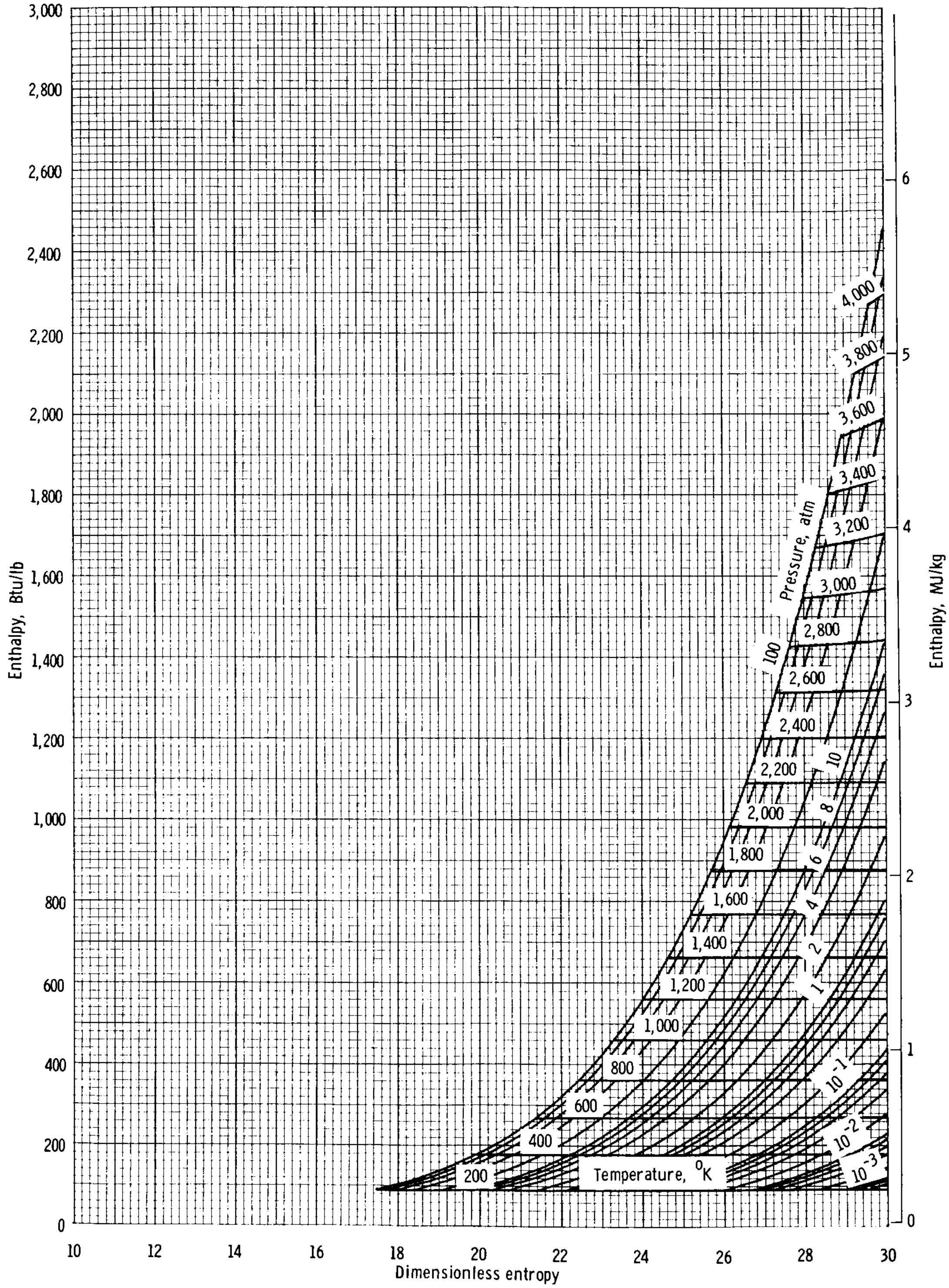


Chart 1

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2.

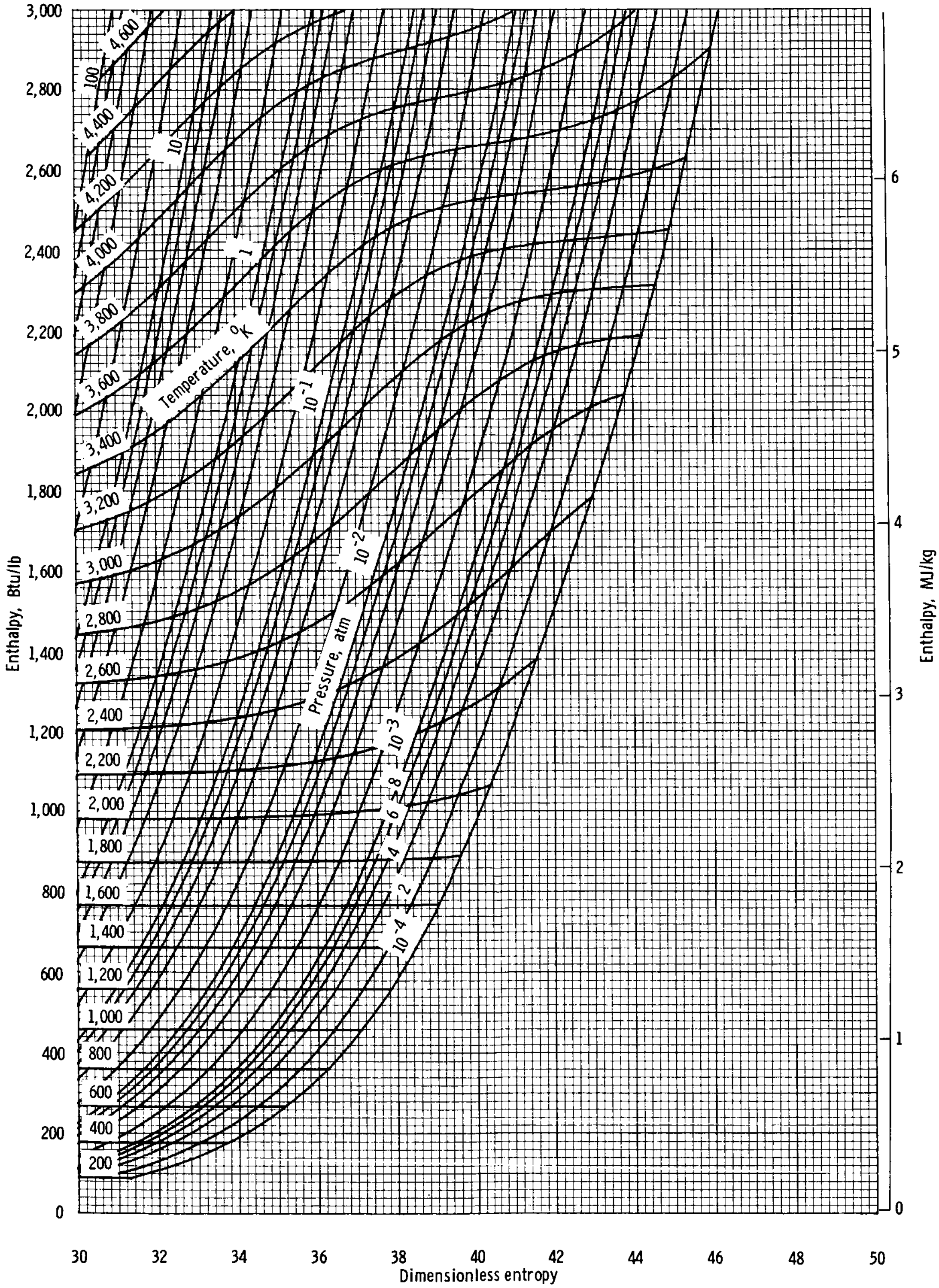


Chart 2

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

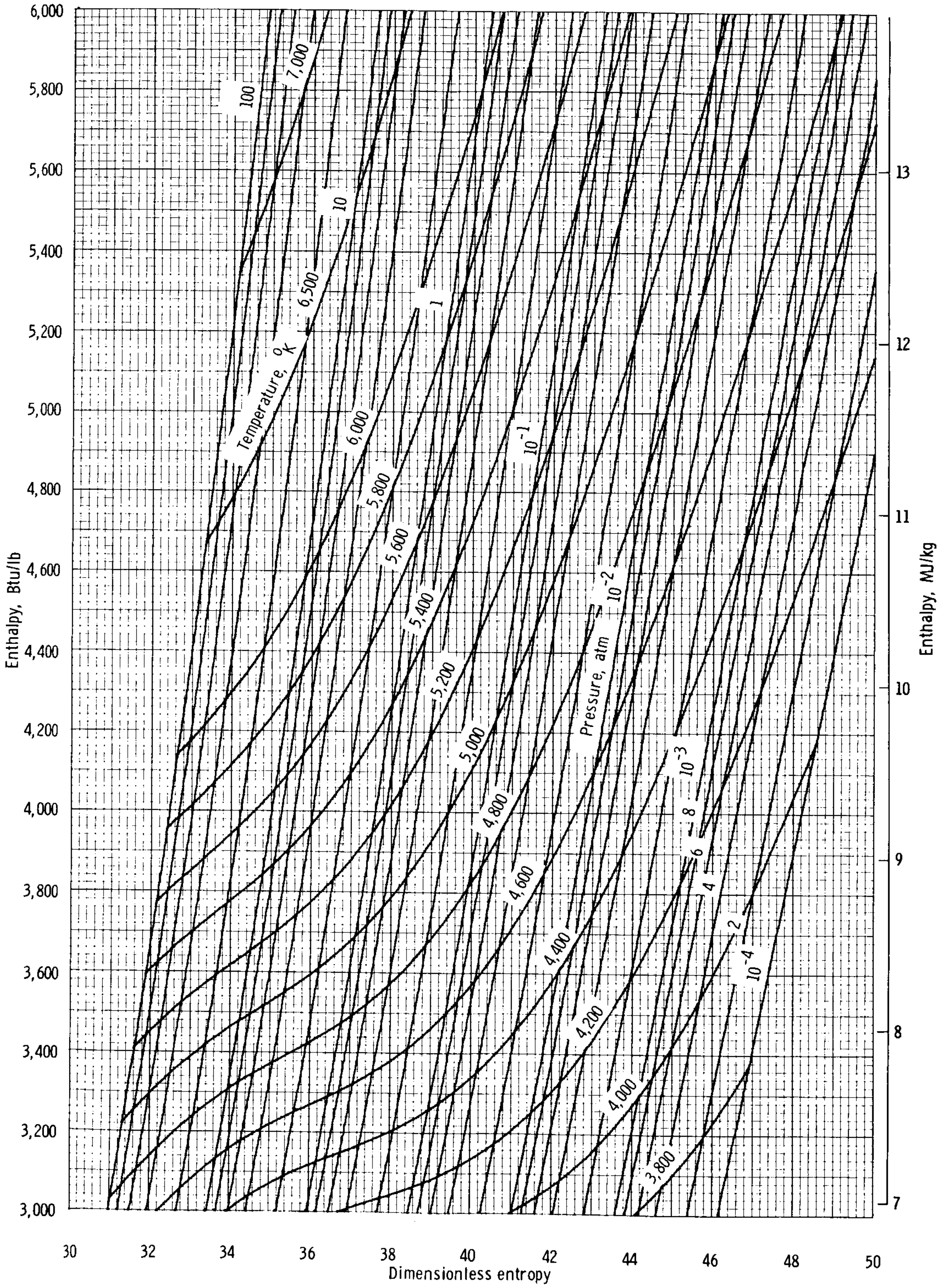


Chart 3

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

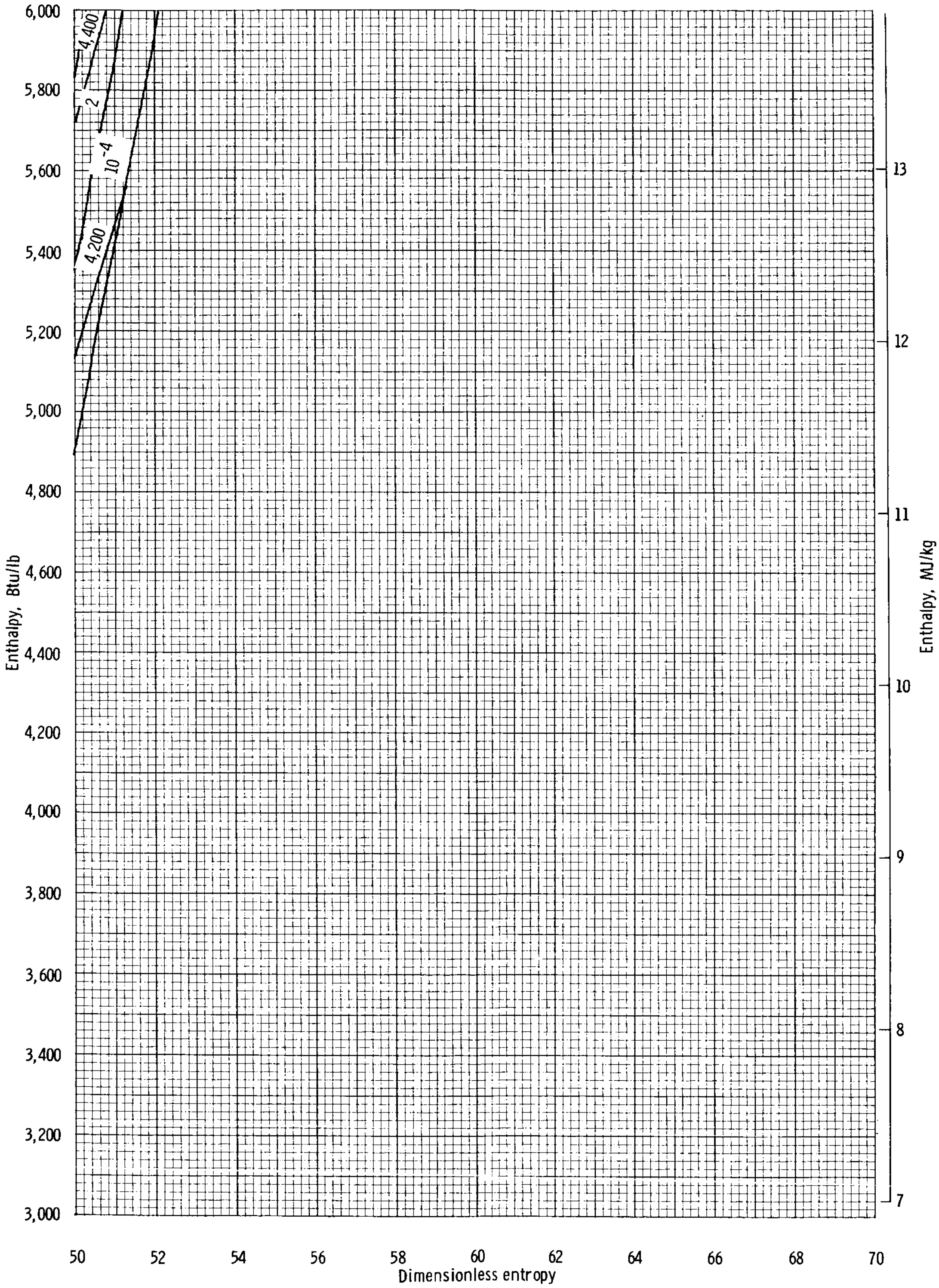


Chart 4

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

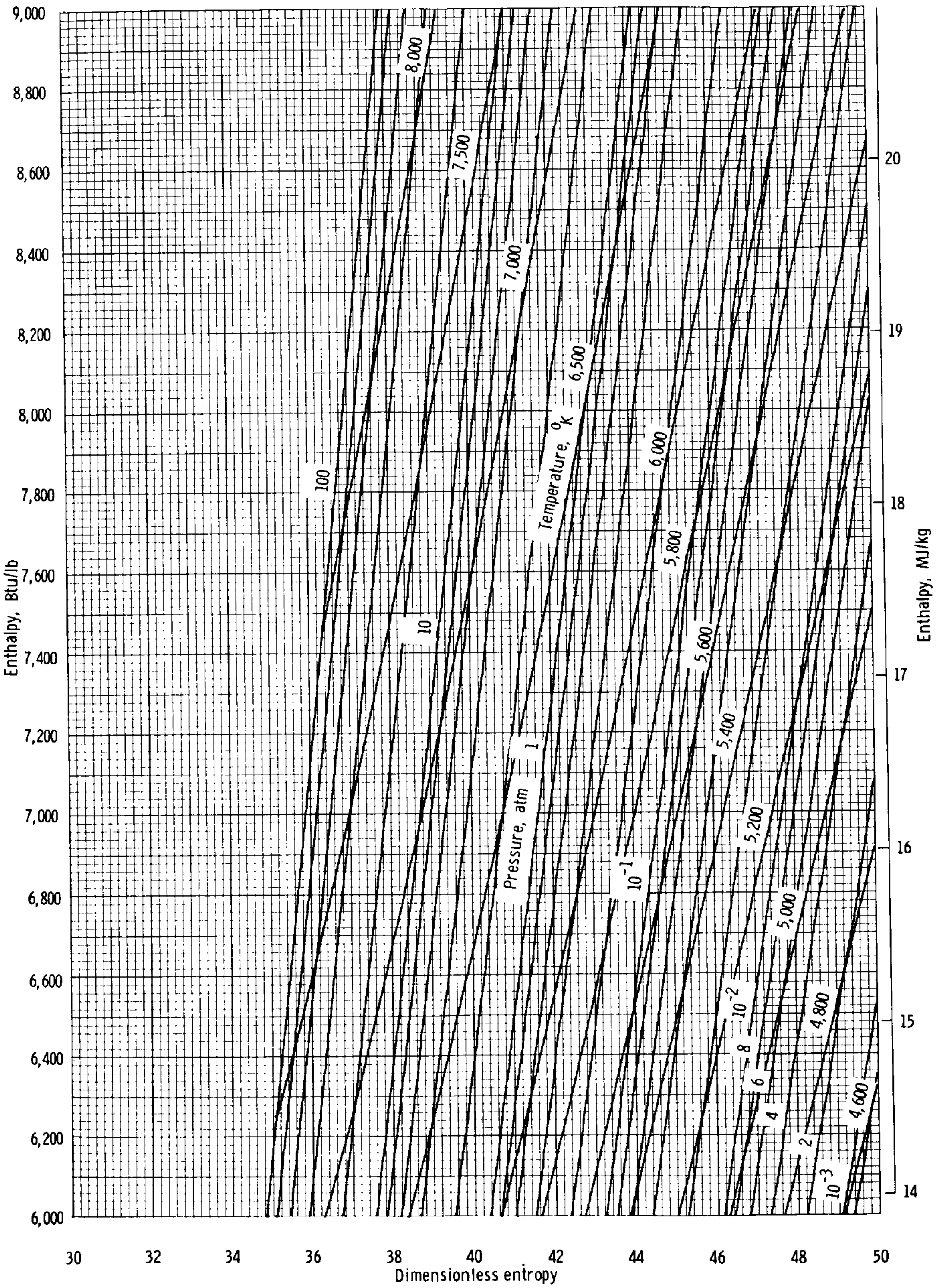


Chart 5

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

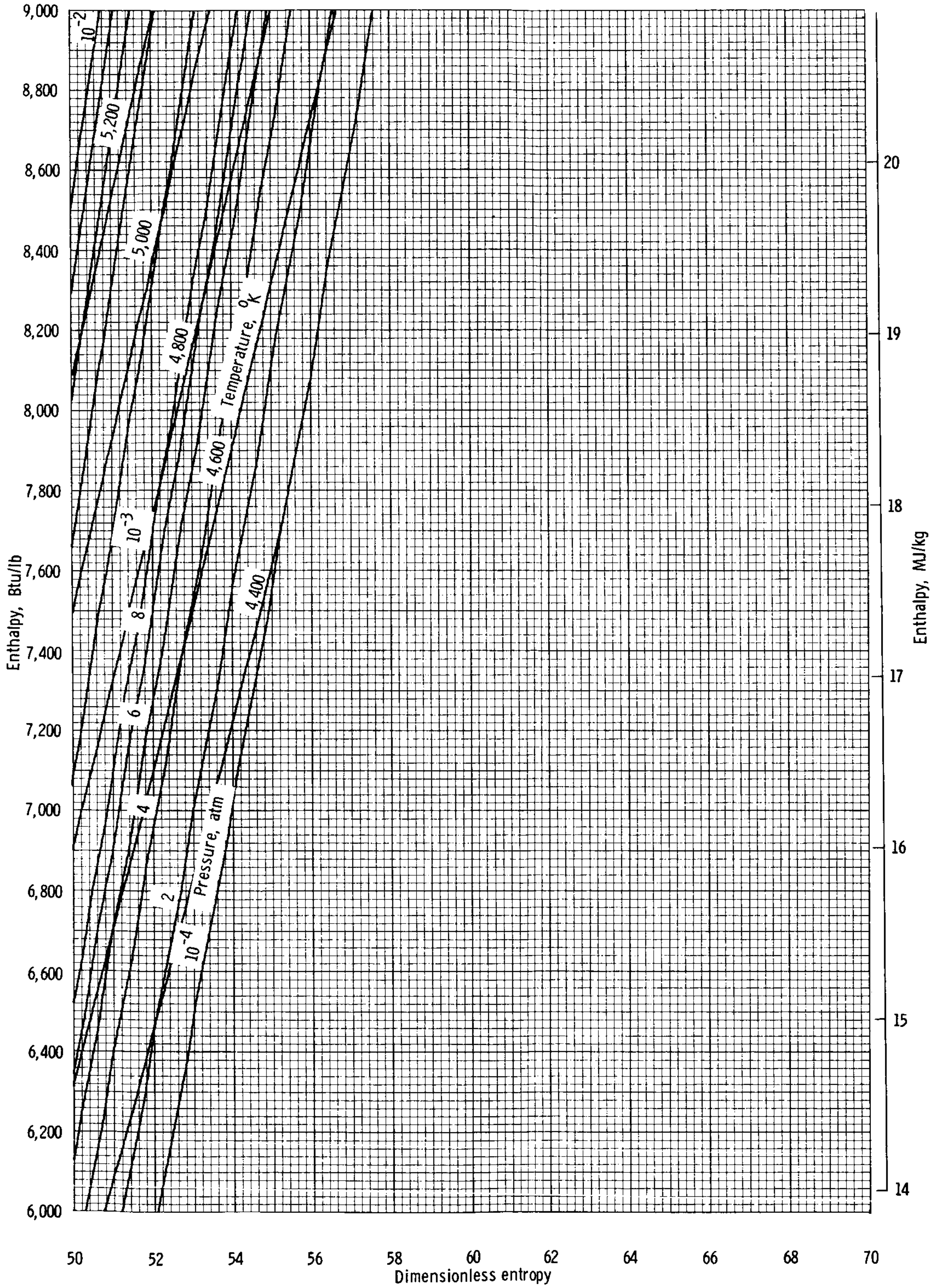


Chart 6

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

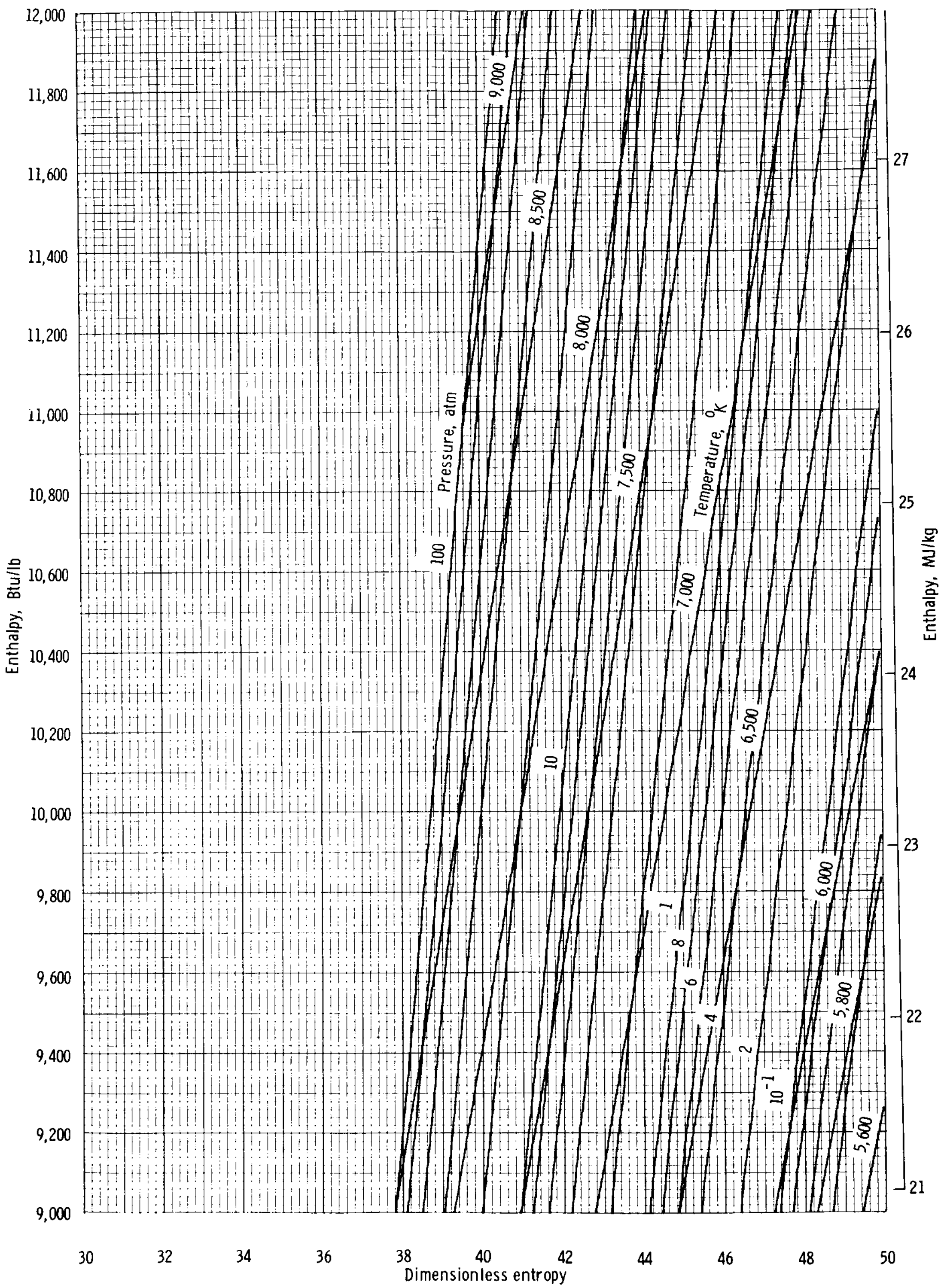


Chart 7

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

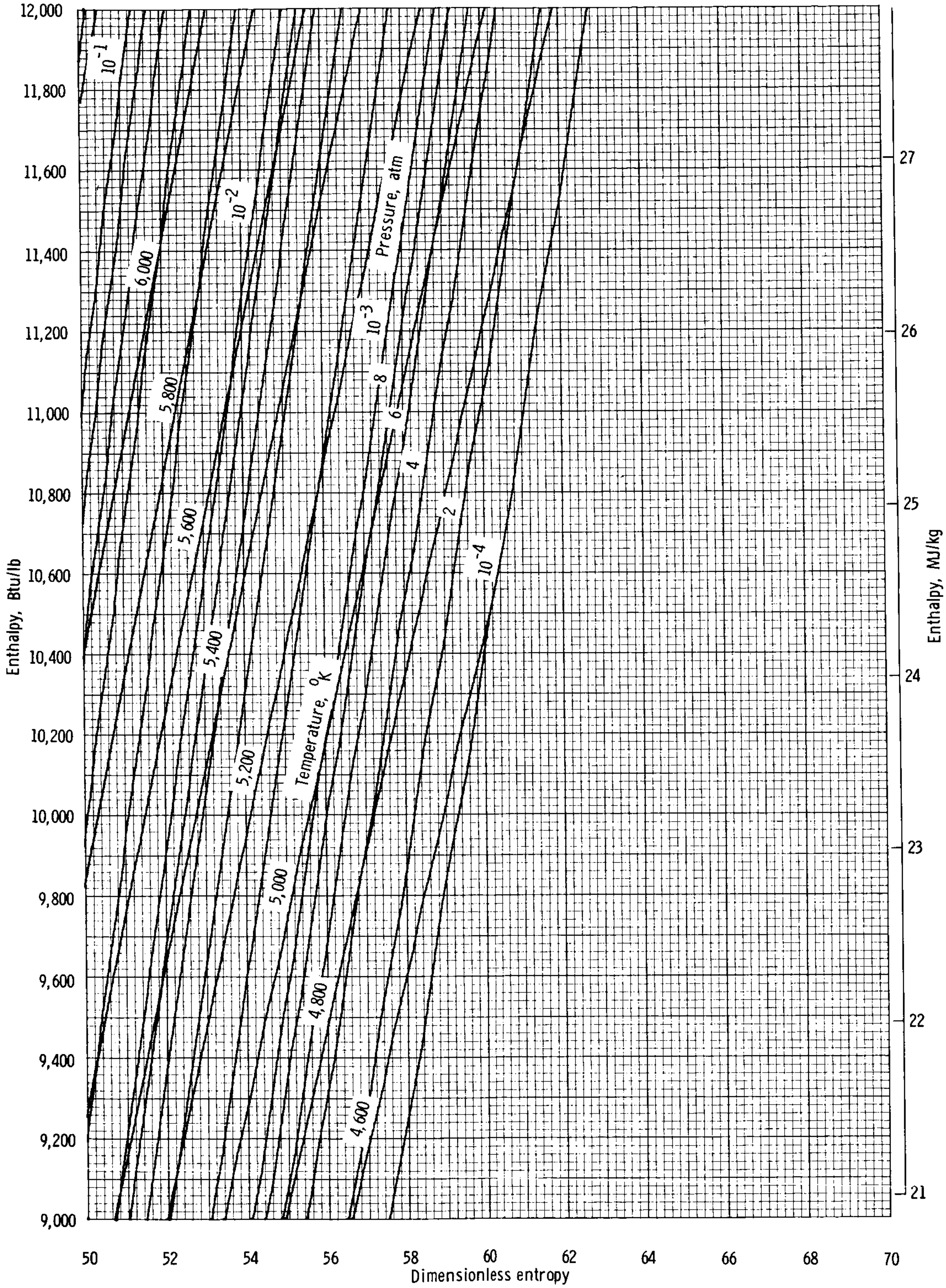


Chart 8

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

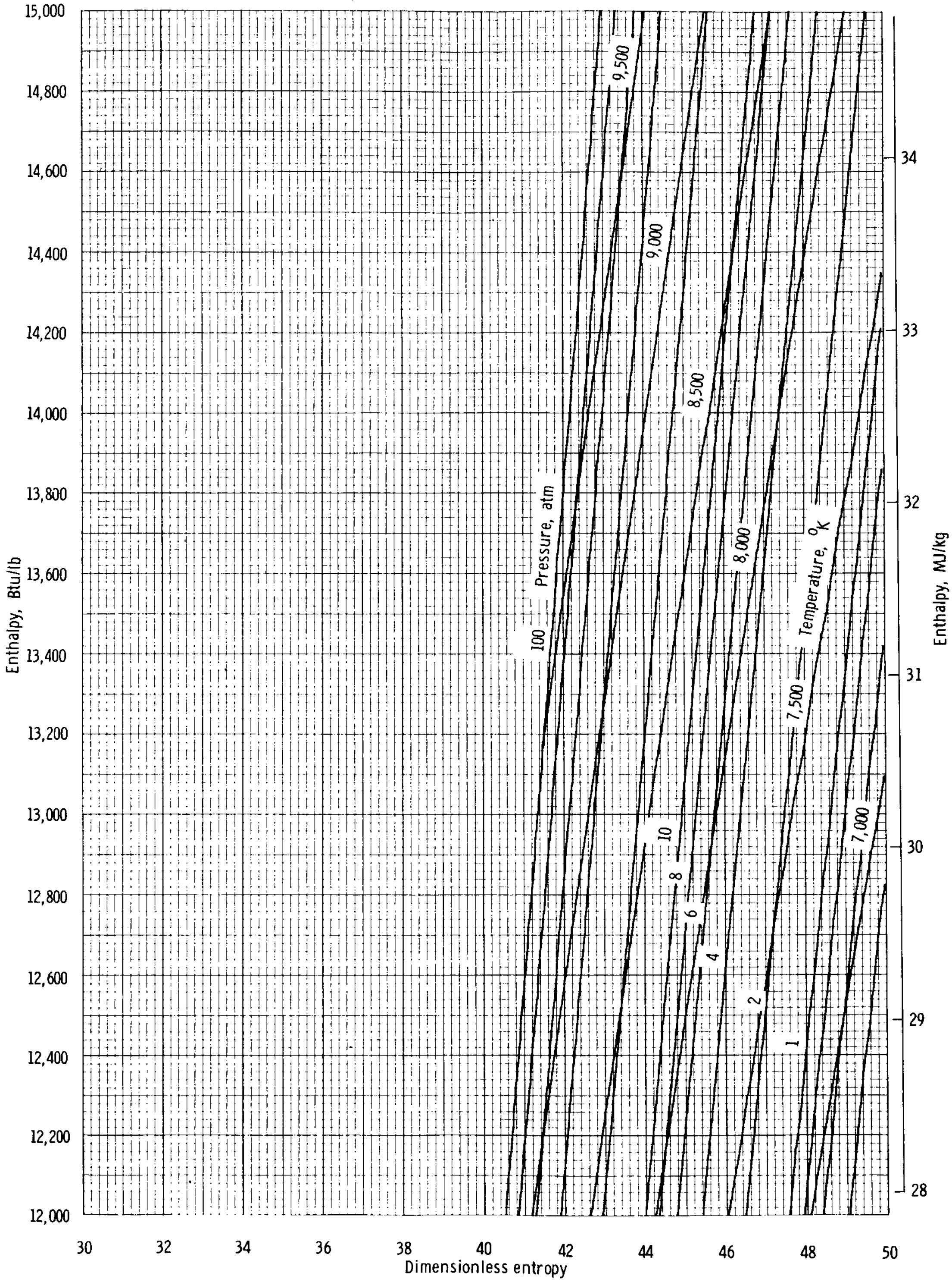


Chart 9

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

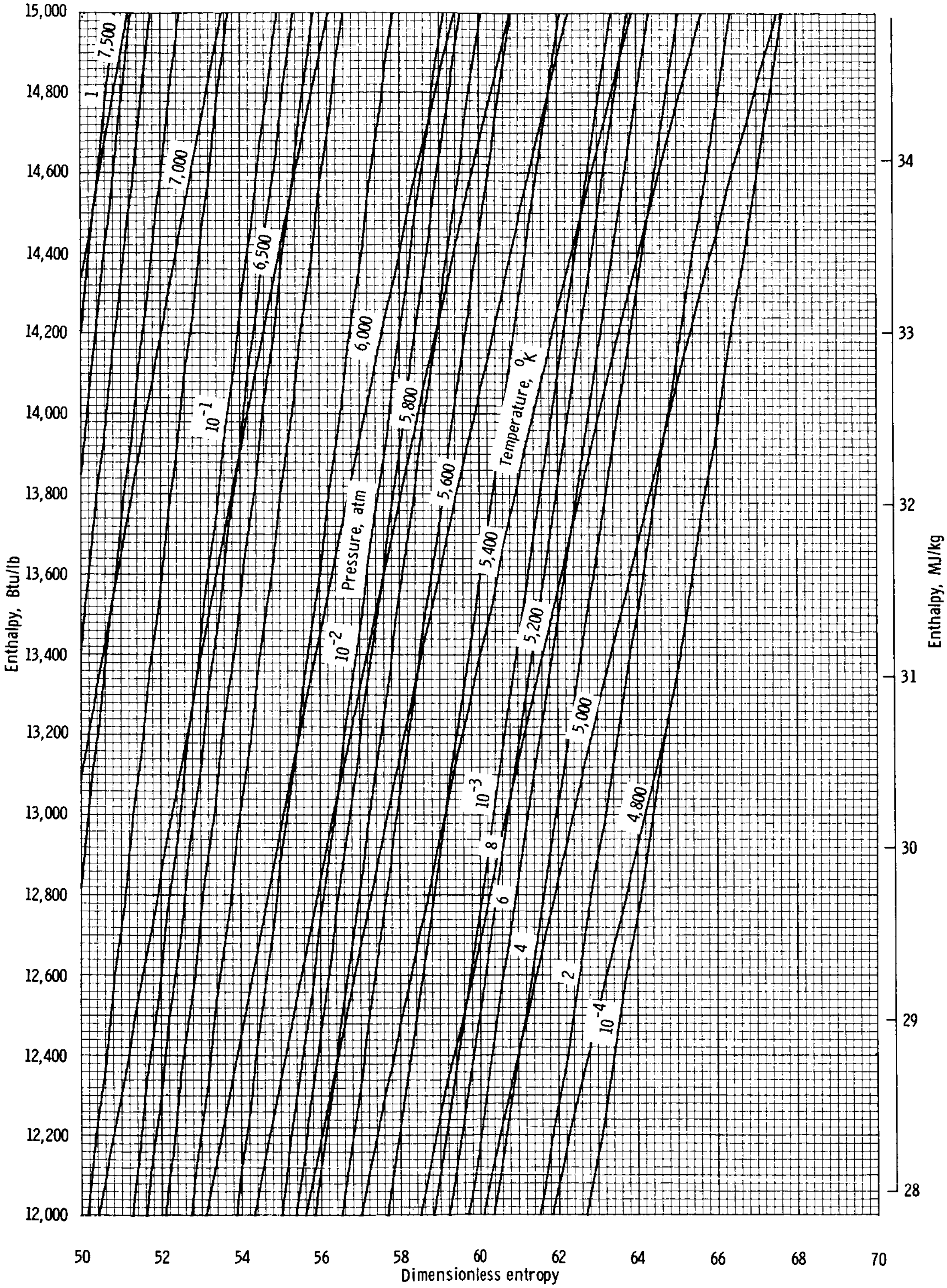


Chart 10

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

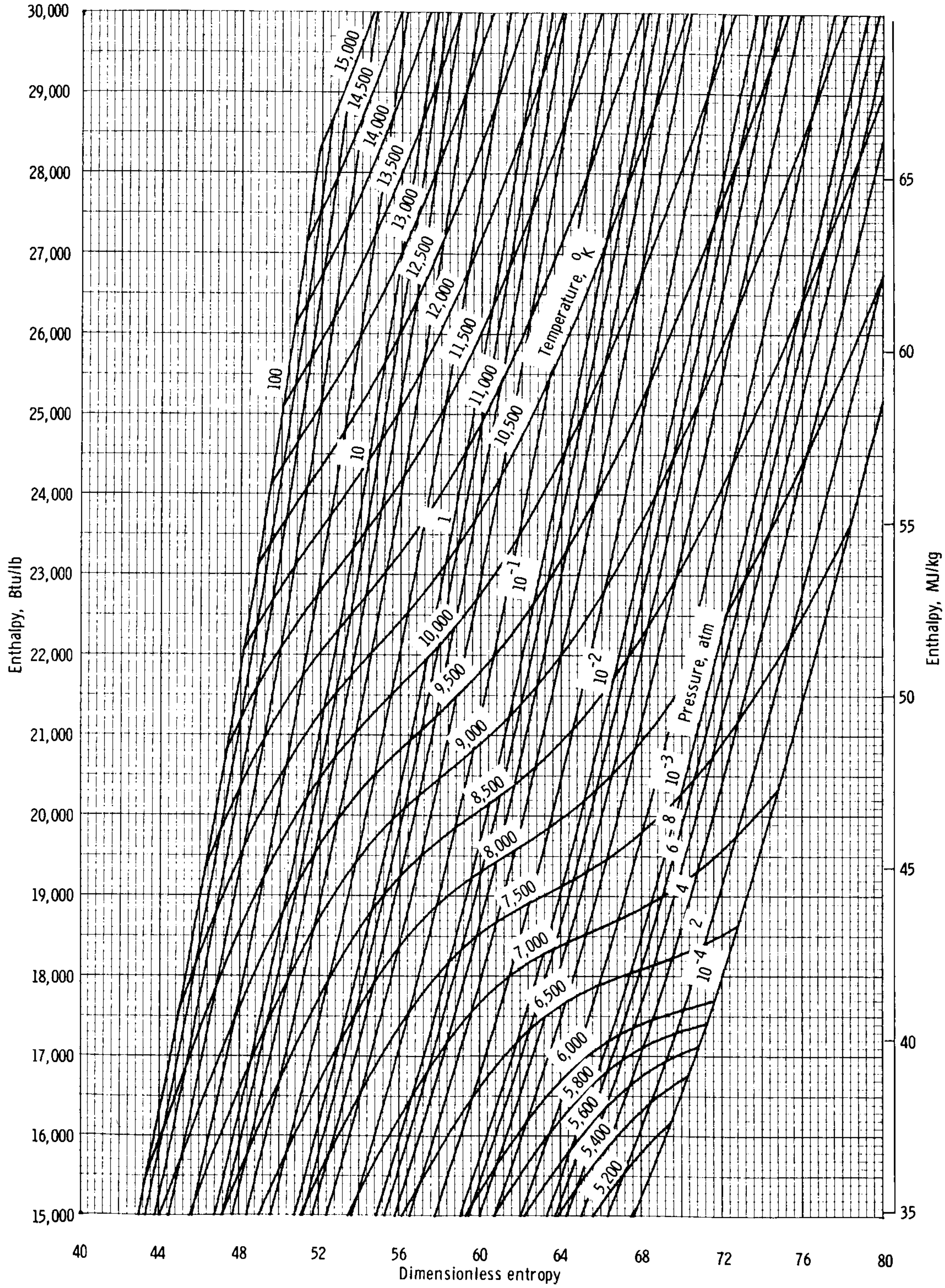


Chart 11

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

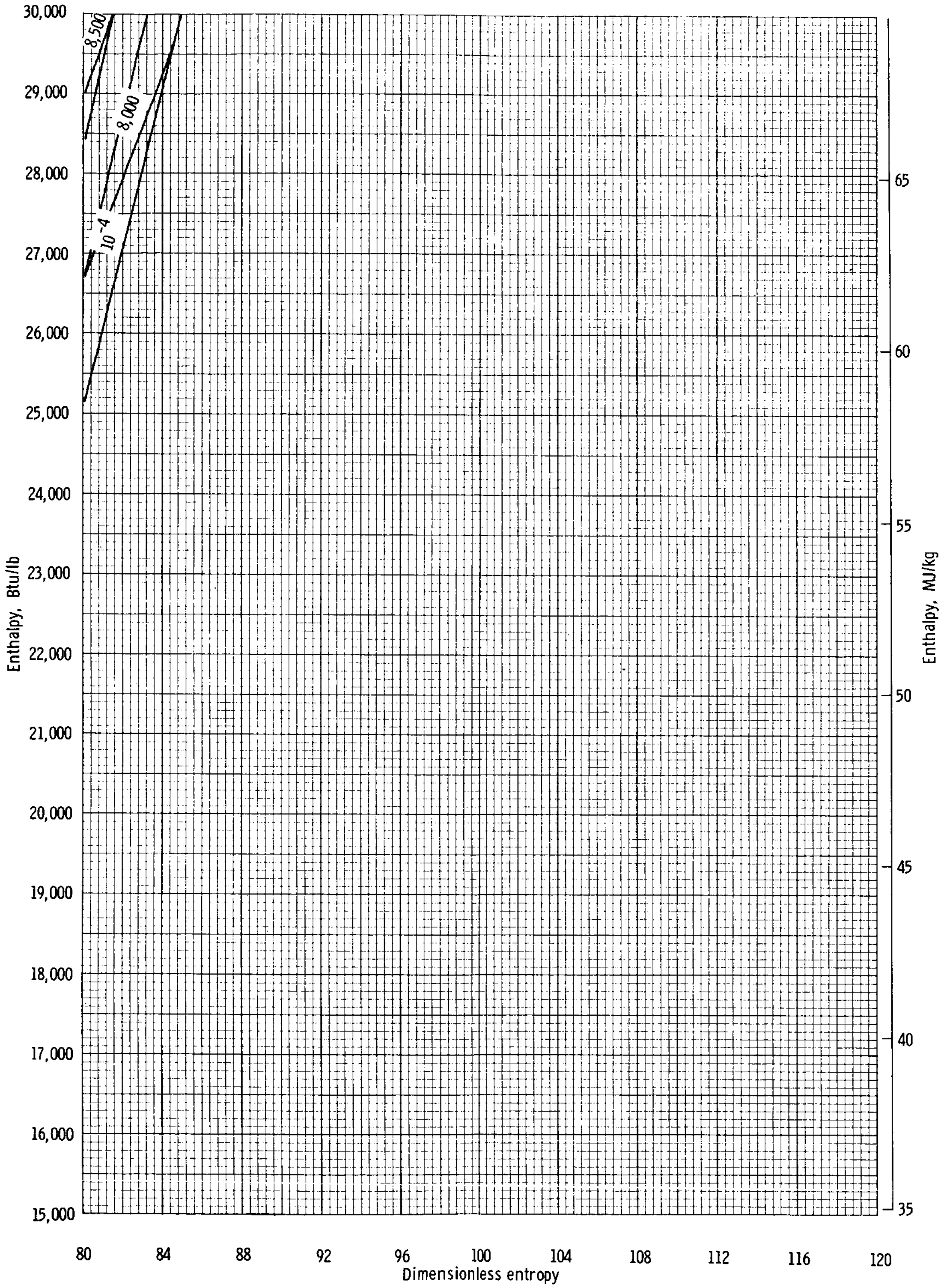


Chart 12

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

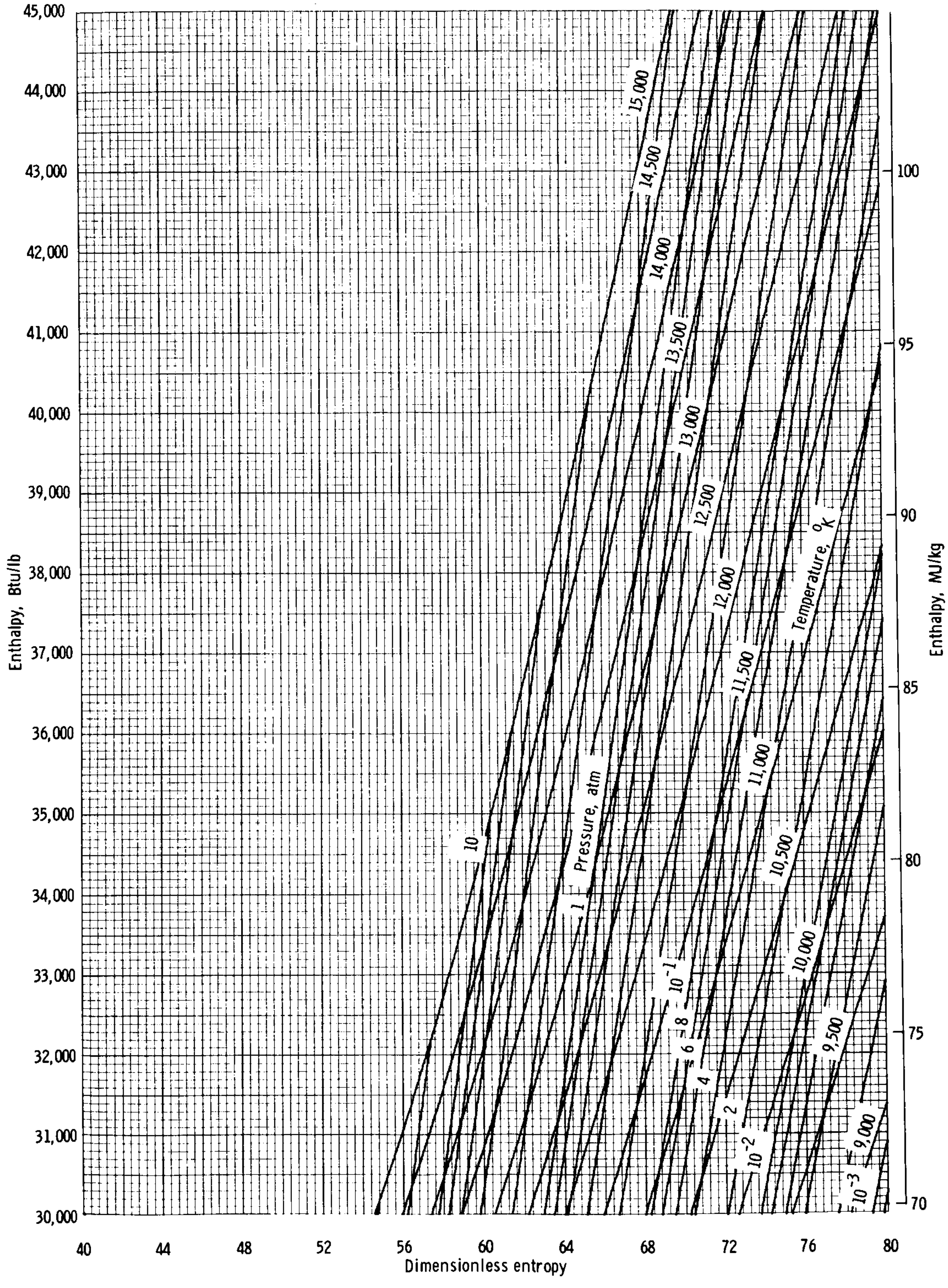


Chart 13

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

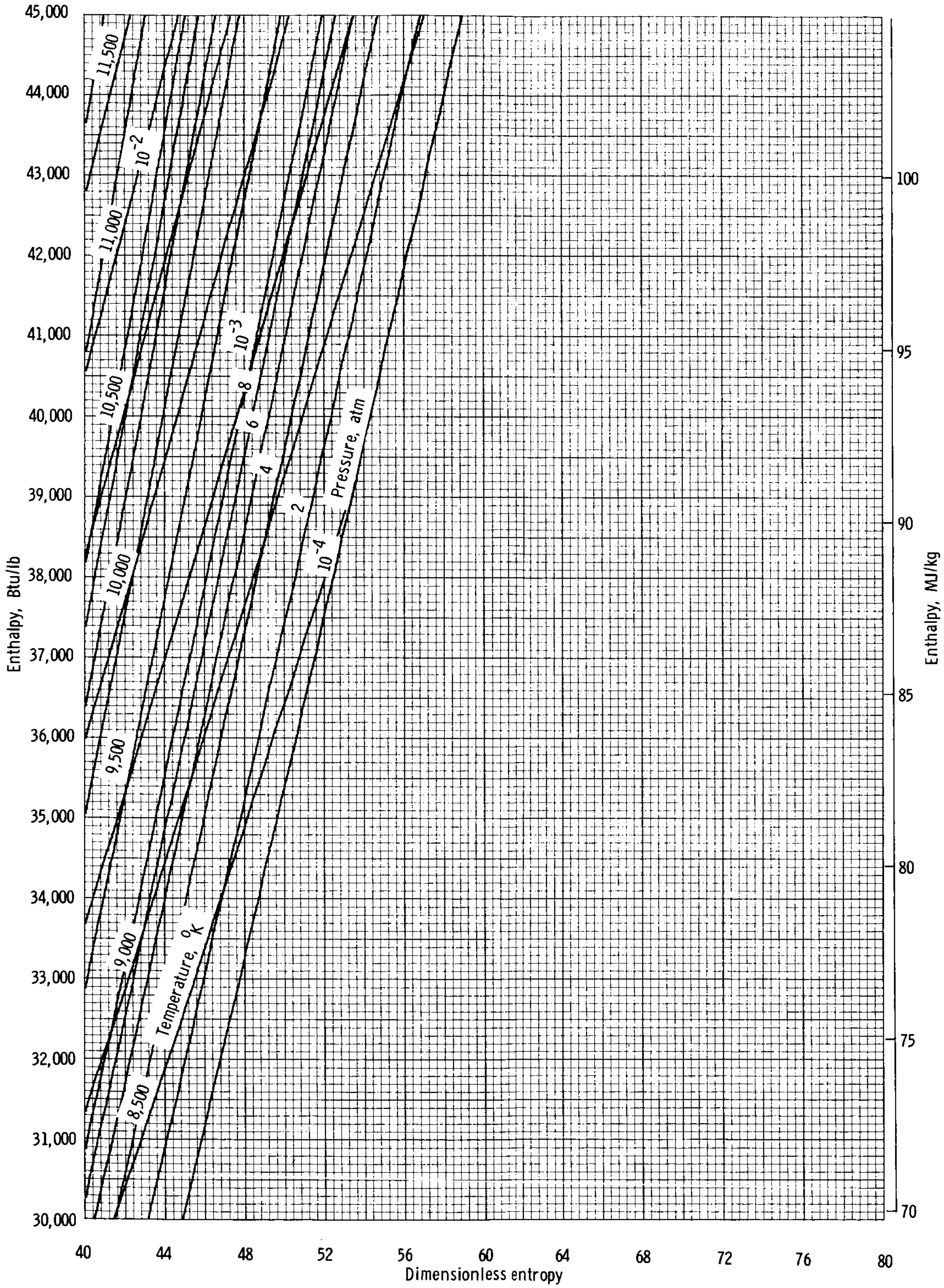


Chart 14

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

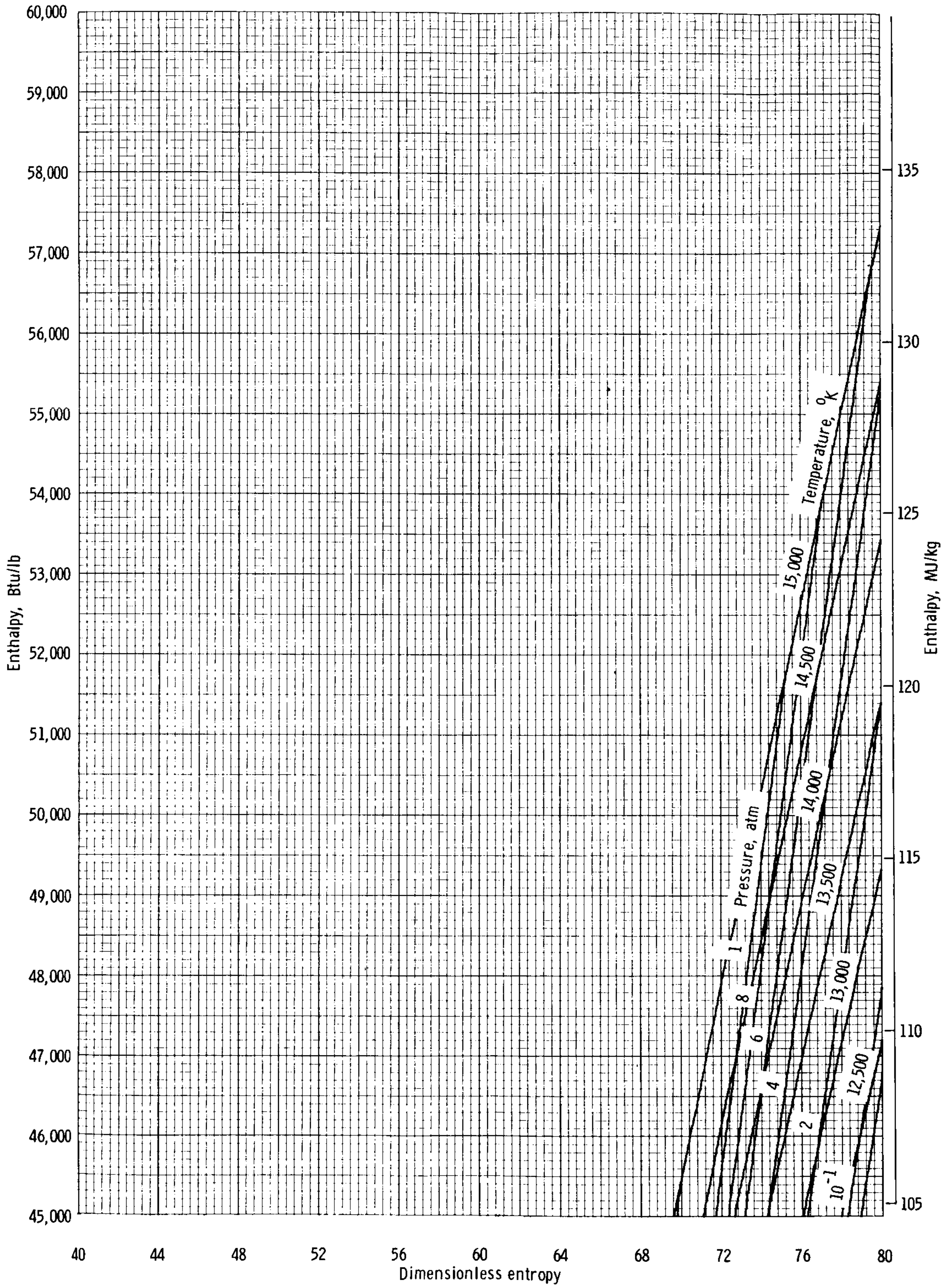


Chart 15

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

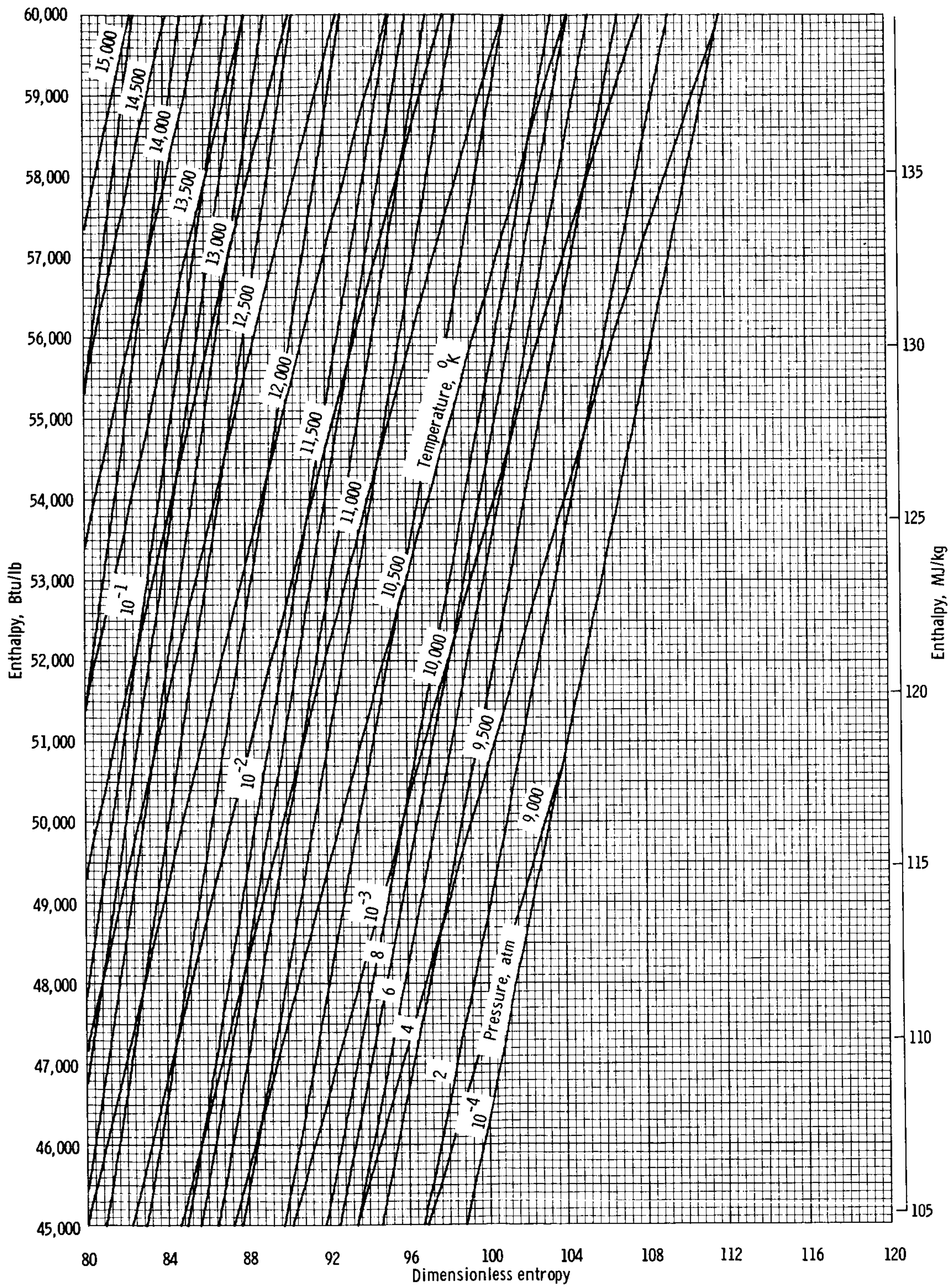


Chart 16

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

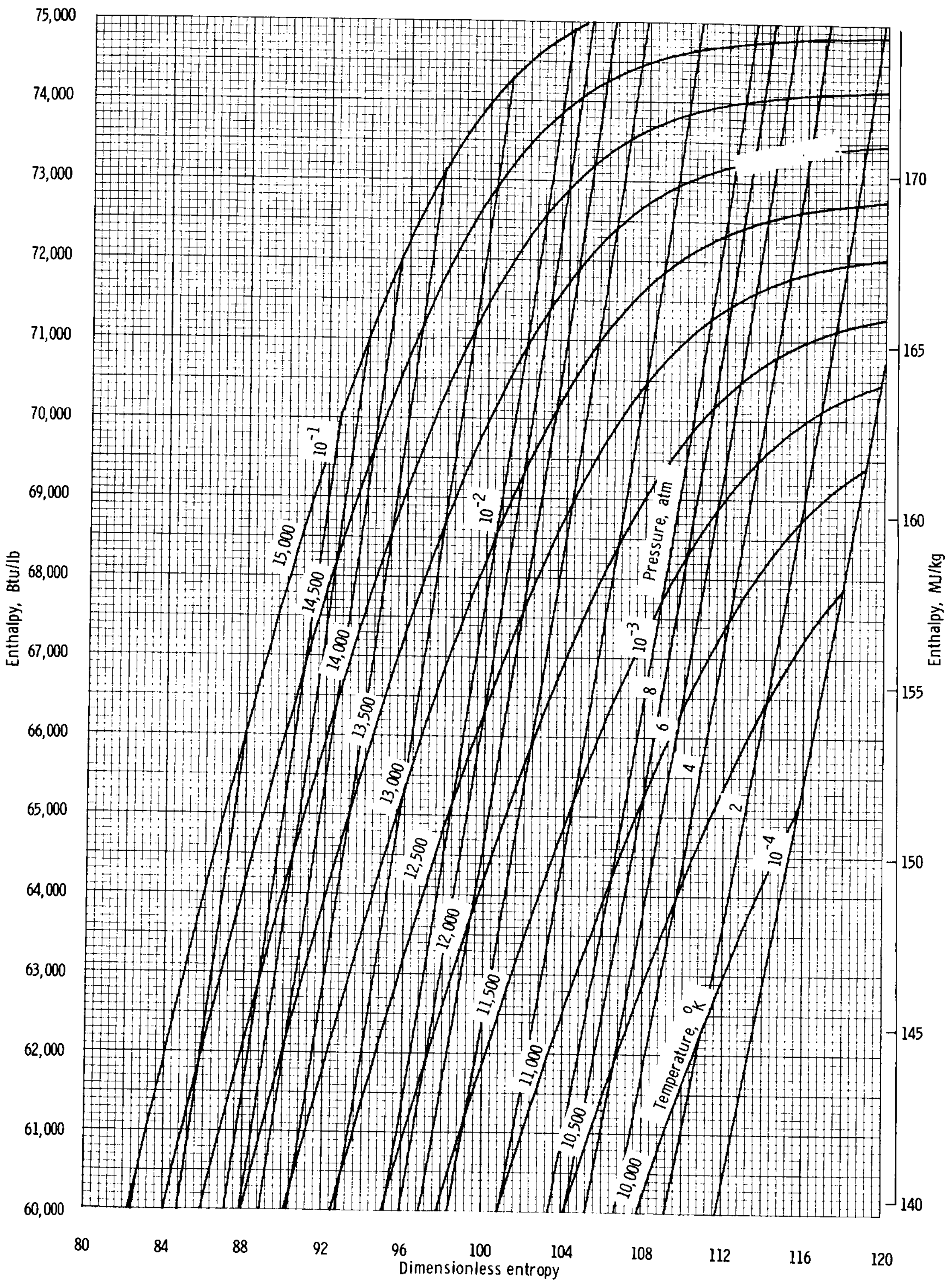


Chart 17

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

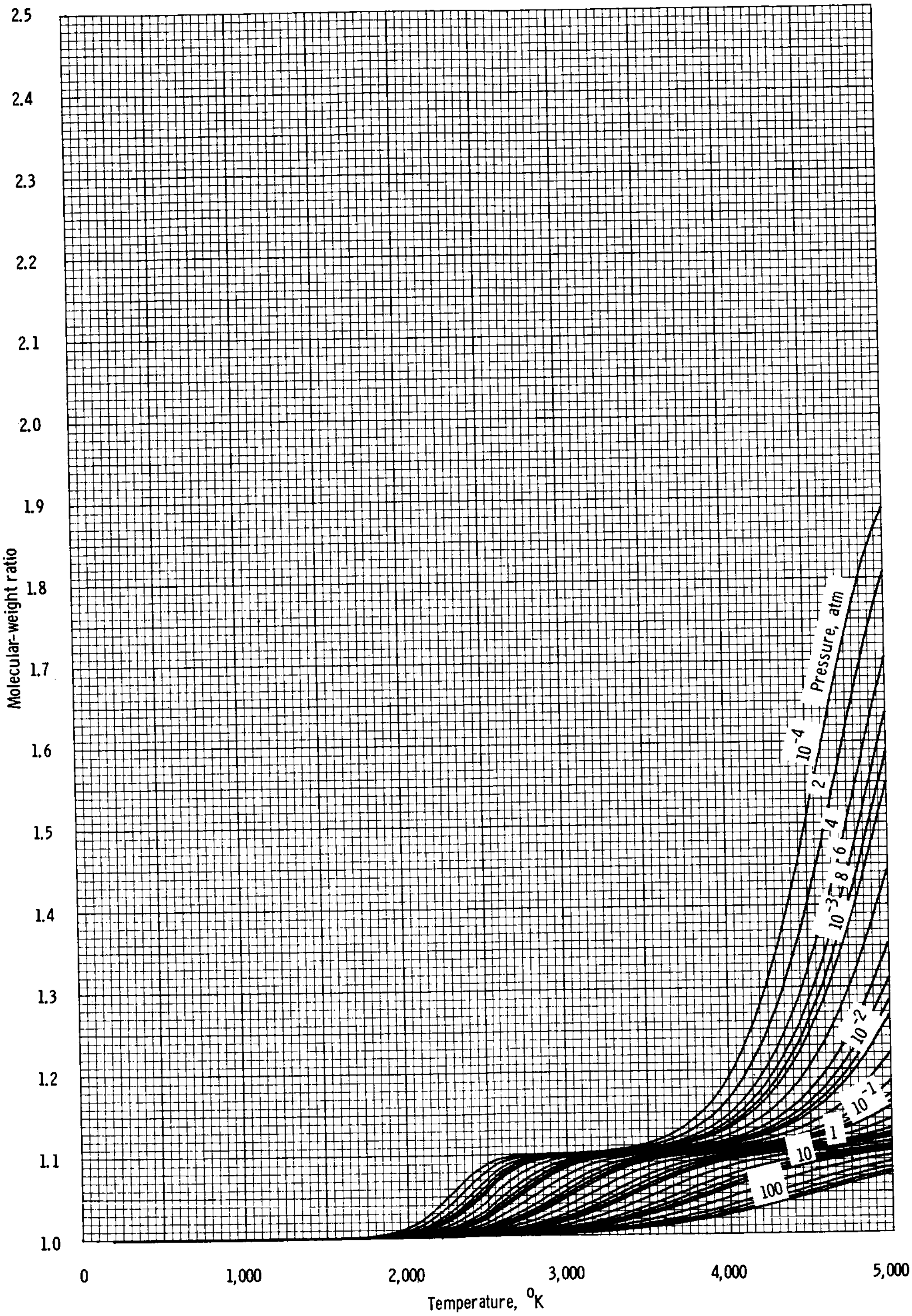


Chart 18

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

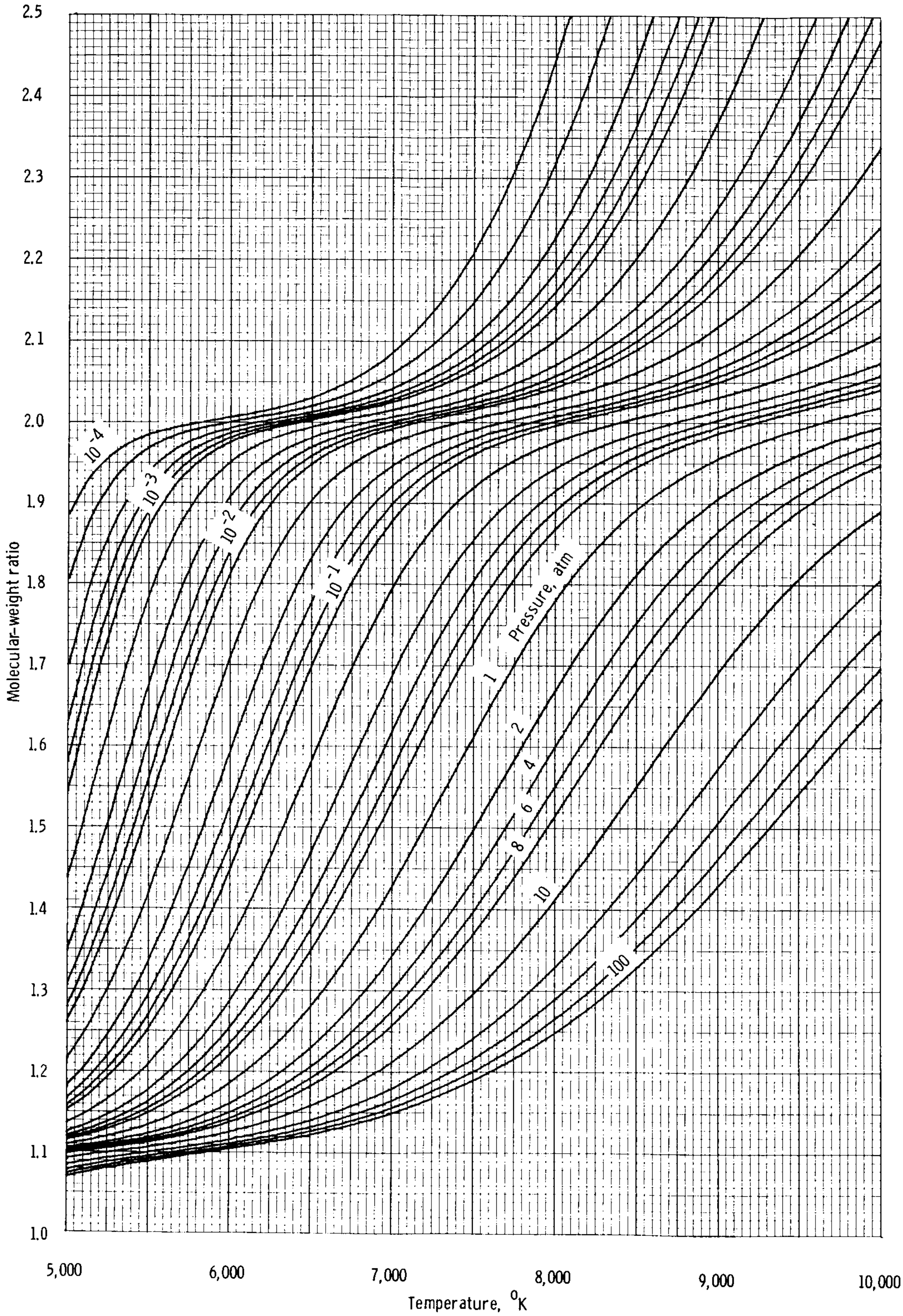


Chart 19

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

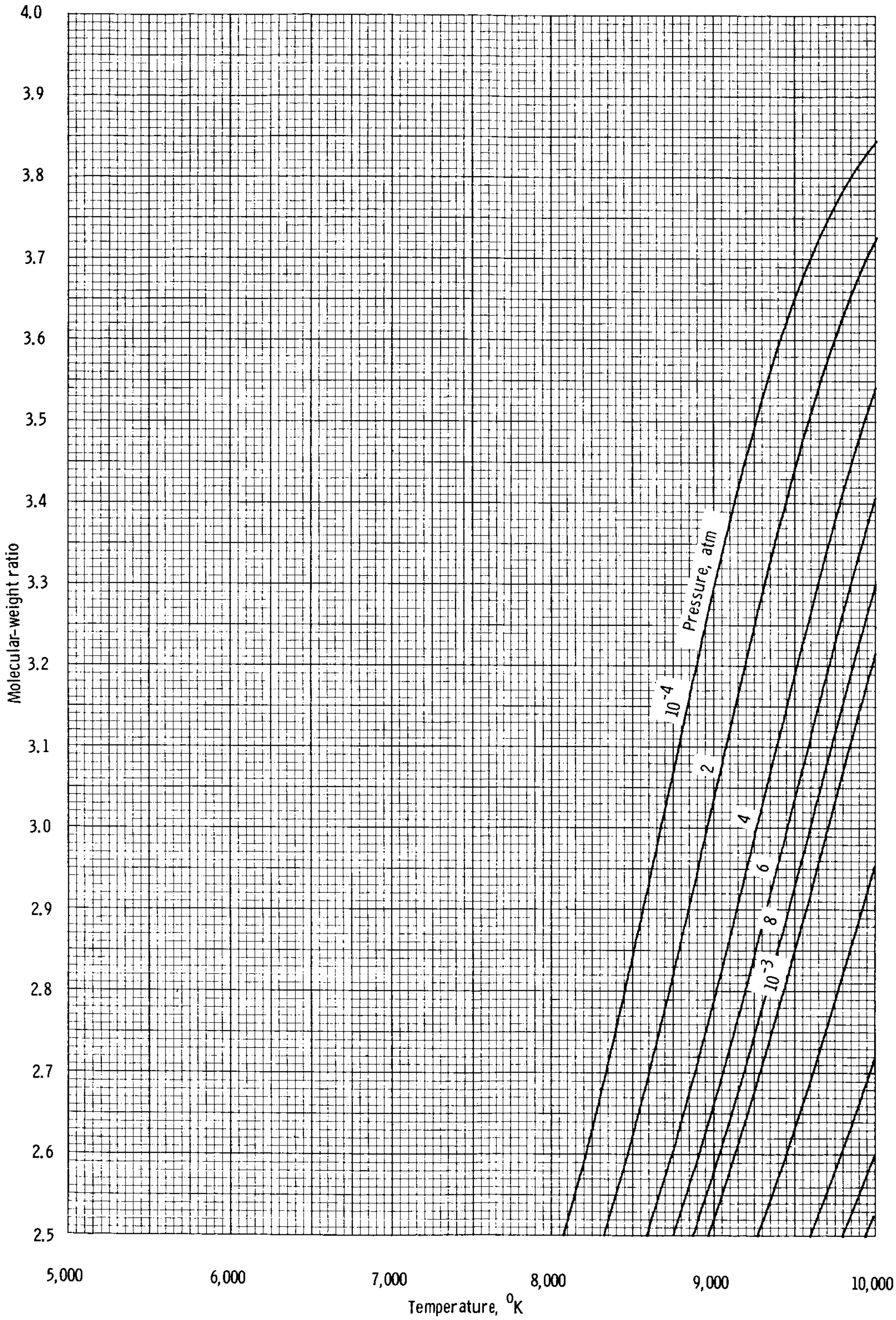


Chart 20

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Continued.

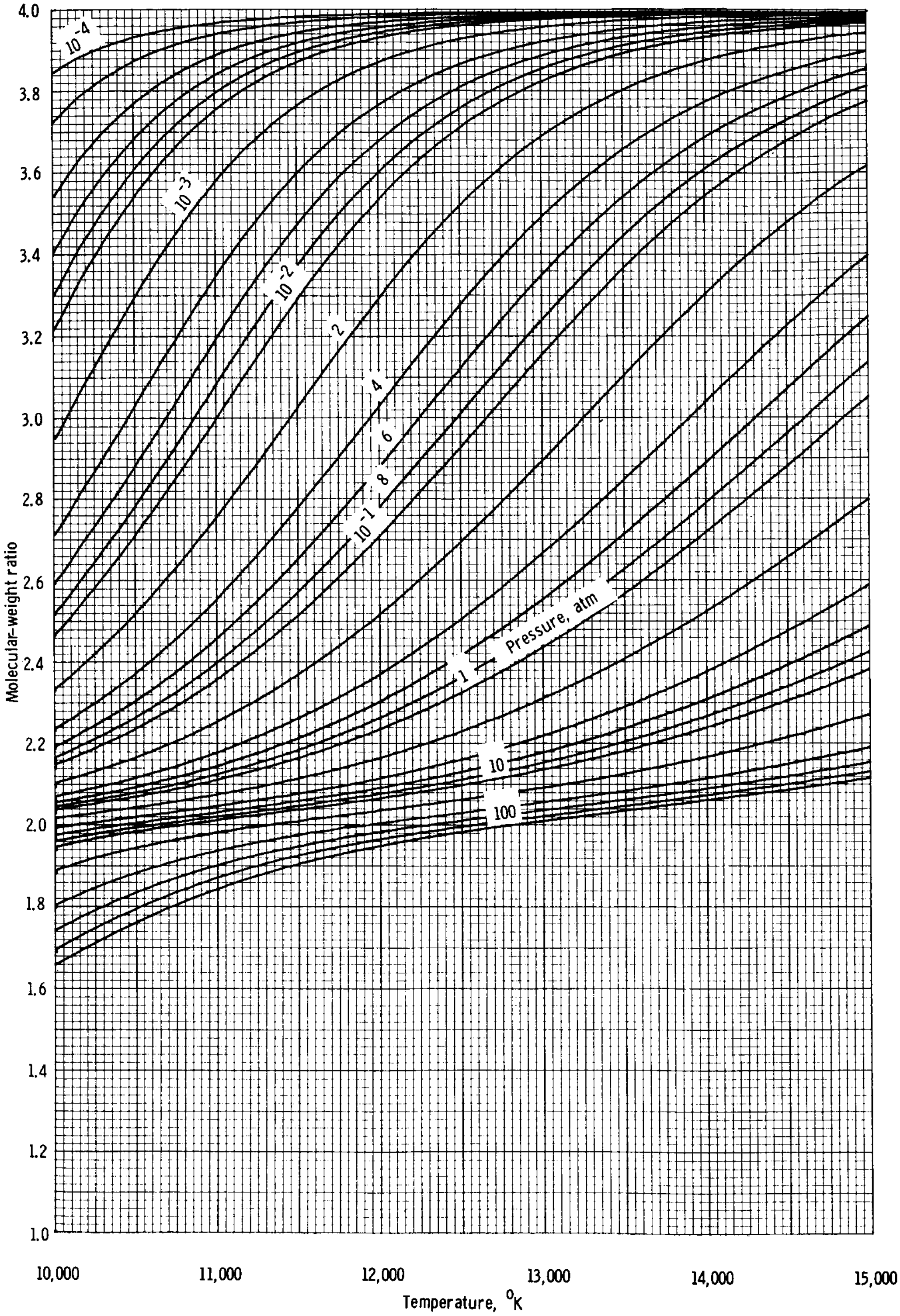


Chart 21

Figure 4.- Thermodynamic charts for 90 percent N_2 and 10 percent O_2. Concluded.

TABLE IV.- THERMODYNAMIC PROPERTIES OF 90 PERCENT N_2 AND 10 PERCENT O_2

(a) Ratio of specific heats γ

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961
600	1.3794	1.3794	1.3794	1.3794	1.3794	1.3794	1.3794
800	1.3580	1.3580	1.3580	1.3580	1.3580	1.3580	1.3580
1,000	1.3402	1.3402	1.3402	1.3402	1.3402	1.3402	1.3402
1,200	1.3272	1.3272	1.3272	1.3271	1.3271	1.3271	1.3271
1,400	1.3178	1.3178	1.3178	1.3178	1.3177	1.3174	1.3165
1,600	1.3110	1.3110	1.3109	1.3106	1.3097	1.3067	1.2977
1,800	1.3059	1.3057	1.3052	1.3033	1.2977	1.2817	1.2436
2,000	1.3018	1.3010	1.2986	1.2914	1.2716	1.2287	1.1715
2,200	1.2980	1.2956	1.2886	1.2692	1.2281	1.1754	1.1446
2,400	1.2939	1.2882	1.2722	1.2368	1.1879	1.1569	1.1597
2,600	1.2888	1.2775	1.2501	1.2060	1.1714	1.1687	1.2306
2,800	1.2824	1.2636	1.2273	1.1890	1.1771	1.2163	1.2922
3,000	1.2745	1.2485	1.2109	1.1882	1.2030	1.2743	1.2874
3,200	1.2656	1.2351	1.2044	1.1998	1.2479	1.2837	1.2444
3,400	1.2568	1.2262	1.2071	1.2236	1.2743	1.2546	1.1882
3,600	1.2493	1.2228	1.2167	1.2522	1.2648	1.2094	1.1452
3,800	1.2440	1.2247	1.2317	1.2646	1.2338	1.1682	1.1274
4,000	1.2415	1.2304	1.2480	1.2540	1.1978	1.1432	1.1336
4,200	1.2417	1.2382	1.2566	1.2296	1.1685	1.1369	1.1591
4,400	1.2441	1.2464	1.2518	1.2025	1.1518	1.1475	1.1923
4,600	1.2478	1.2524	1.2365	1.1801	1.1483	1.1713	1.2082
4,800	1.2519	1.2530	1.2173	1.1660	1.1571	1.1998	1.1924
5,000	1.2553	1.2471	1.1993	1.1611	1.1756	1.2176	1.1716
5,200	1.2571	1.2363	1.1858	1.1649	1.1996	1.2127	1.1777
5,400	1.2565	1.2235	1.1779	1.1765	1.2211	1.1941	1.2154
5,600	1.2530	1.2114	1.1762	1.1939	1.2307	1.1842	1.2603
5,800	1.2470	1.2018	1.1801	1.2140	1.2246	1.1950	1.2769
6,000	1.2394	1.1956	1.1893	1.2322	1.2105	1.2229	1.2602
6,500	1.2209	1.1964	1.2267	1.2409	1.2086	1.2563	1.1864
7,000	1.2124	1.2176	1.2584	1.2180	1.2459	1.2069	1.1532
7,500	1.2175	1.2496	1.2553	1.2273	1.2310	1.1710	1.1626
8,000	1.2345	1.2752	1.2373	1.2420	1.1977	1.1664	1.2011
8,500	1.2589	1.2794	1.2362	1.2291	1.1807	1.1872	1.2415
9,000	1.2834	1.2668	1.2434	1.2091	1.1835	1.2236	1.2424
9,500	1.2995	1.2553	1.2405	1.1982	1.2027	1.2561	1.2138
10,000	1.3026	1.2532	1.2301	1.1996	1.2325	1.2614	1.2114
10,500	1.2953	1.2548	1.2215	1.2121	1.2629	1.2421	1.2595
11,000	1.2855	1.2539	1.2191	1.2333	1.2807	1.2292	1.3466
11,500	1.2790	1.2502	1.2237	1.2590	1.2787	1.2452	1.4372
12,000	1.2770	1.2468	1.2348	1.2837	1.2651	1.2931	1.5029
12,500	1.2774	1.2460	1.2513	1.3009	1.2565	1.3612	1.5412
13,000	1.2781	1.2487	1.2712	1.3065	1.2646	1.4301	1.5613
13,500	1.2784	1.2552	1.2924	1.3019	1.2925	1.4851	1.5714
14,000	1.2788	1.2651	1.3119	1.2938	1.3363	1.5226	1.5764
14,500	1.2800	1.2781	1.3271	1.2896	1.3876	1.5461	1.5790
15,000	1.2827	1.2932	1.3360	1.2947	1.4371	1.5602	1.5804

TABLE IV.- THERMODYNAMIC PROPERTIES OF 90 PERCENT N_2 AND 10 PERCENT O_2 - Concluded

(b) Dimensionless speed-of-sound parameter $a^2\rho/p$

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961	1.3961
600	1.3794	1.3794	1.3794	1.3794	1.3794	1.3794	1.3794
800	1.3580	1.3580	1.3580	1.3580	1.3580	1.3580	1.3580
1,000	1.3402	1.3402	1.3402	1.3402	1.3402	1.3402	1.3402
1,200	1.3272	1.3272	1.3272	1.3271	1.3271	1.3271	1.3271
1,400	1.3178	1.3178	1.3178	1.3178	1.3177	1.3174	1.3165
1,600	1.3110	1.3110	1.3109	1.3106	1.3096	1.3066	1.2976
1,800	1.3059	1.3057	1.3051	1.3033	1.2976	1.2812	1.2423
2,000	1.3018	1.3010	1.2986	1.2912	1.2708	1.2265	1.1655
2,200	1.2980	1.2955	1.2882	1.2683	1.2253	1.1679	1.1286
2,400	1.2938	1.2879	1.2713	1.2340	1.1803	1.1407	1.1439
2,600	1.2886	1.2767	1.2477	1.1993	1.1562	1.1512	1.2254
2,800	1.2818	1.2618	1.2222	1.1763	1.1580	1.2081	1.2909
3,000	1.2732	1.2449	1.2014	1.1699	1.1896	1.2716	1.2867
3,200	1.2634	1.2287	1.1896	1.1813	1.2418	1.2825	1.2430
3,400	1.2530	1.2160	1.1882	1.2107	1.2716	1.2531	1.1844
3,600	1.2433	1.2085	1.1975	1.2452	1.2629	1.2063	1.1362
3,800	1.2352	1.2066	1.2162	1.2607	1.2312	1.1613	1.1073
4,000	1.2295	1.2104	1.2374	1.2509	1.1928	1.1289	1.0933
4,200	1.2264	1.2189	1.2497	1.2258	1.1591	1.1098	1.0881
4,400	1.2259	1.2300	1.2466	1.1964	1.1348	1.1001	1.0881
4,600	1.2278	1.2395	1.2314	1.1700	1.1195	1.0965	1.0918
4,800	1.2314	1.2431	1.2107	1.1494	1.1109	1.0966	1.1001
5,000	1.2356	1.2388	1.1898	1.1351	1.1070	1.0998	1.1171
5,200	1.2392	1.2282	1.1717	1.1259	1.1063	1.1062	1.1499
5,400	1.2407	1.2144	1.1574	1.1207	1.1081	1.1175	1.2015
5,600	1.2390	1.2000	1.1469	1.1184	1.1120	1.1371	1.2527
5,800	1.2342	1.1867	1.1397	1.1182	1.1185	1.1680	1.2720
6,000	1.2268	1.1754	1.1351	1.1199	1.1288	1.2073	1.2556
6,500	1.2044	1.1567	1.1321	1.1313	1.1792	1.2499	1.1769
7,000	1.1854	1.1490	1.1372	1.1576	1.2348	1.1980	1.1294
7,500	1.1736	1.1487	1.1495	1.2010	1.2222	1.1522	1.1101
8,000	1.1679	1.1533	1.1712	1.2285	1.1836	1.1283	1.1048
8,500	1.1669	1.1623	1.2007	1.2171	1.1553	1.1184	1.1069
9,000	1.1693	1.1762	1.2229	1.1923	1.1394	1.1164	1.1151
9,500	1.1744	1.1948	1.2246	1.1718	1.1322	1.1195	1.1330
10,000	1.1822	1.2145	1.2126	1.1585	1.1306	1.1272	1.1706
10,500	1.1927	1.2283	1.1980	1.1512	1.1329	1.1413	1.2400
11,000	1.2055	1.2322	1.1861	1.1484	1.1384	1.1666	1.3370
11,500	1.2196	1.2284	1.1779	1.1488	1.1476	1.2094	1.4323
12,000	1.2329	1.2213	1.1730	1.1518	1.1619	1.2729	1.5003
12,500	1.2429	1.2140	1.1709	1.1570	1.1840	1.3496	1.5398
13,000	1.2485	1.2080	1.1710	1.1646	1.2166	1.4233	1.5605
13,500	1.2501	1.2036	1.1729	1.1751	1.2613	1.4810	1.5709
14,000	1.2490	1.2010	1.1764	1.1895	1.3159	1.5201	1.5762
14,500	1.2466	1.1998	1.1814	1.2089	1.3741	1.5445	1.5789
15,000	1.2438	1.2000	1.1879	1.2345	1.4281	1.5592	1.5803

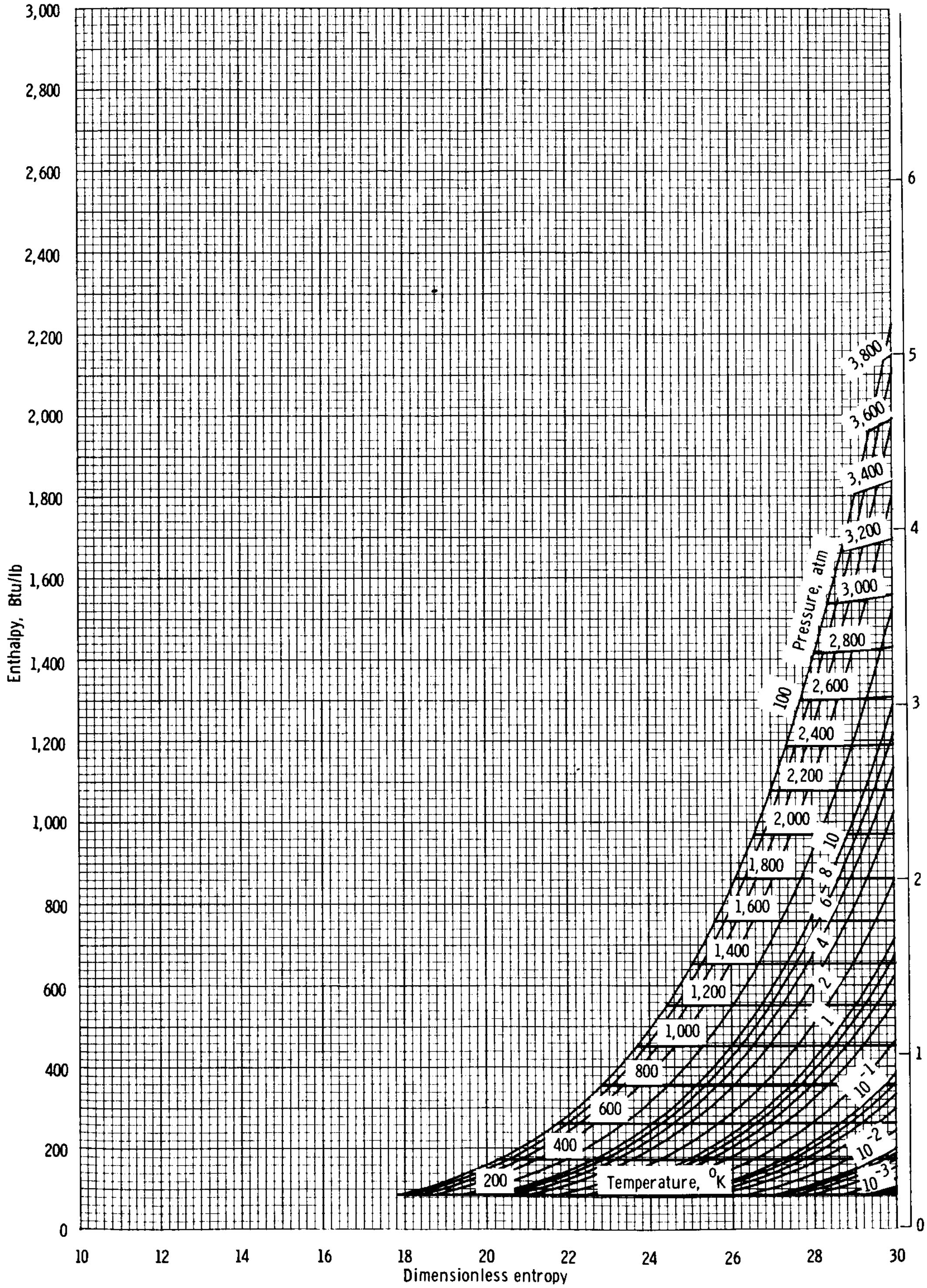


Chart 1

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2.

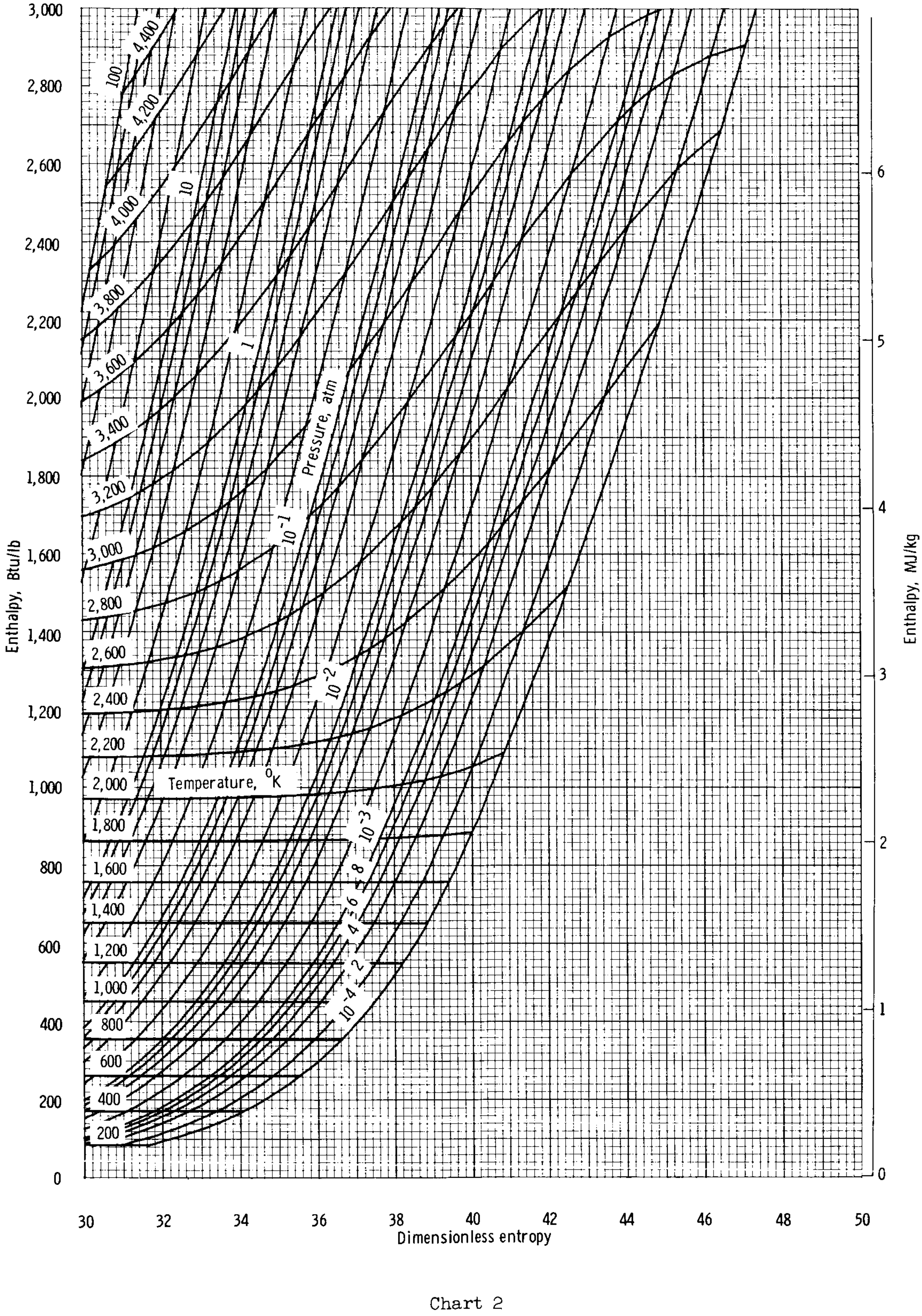


Chart 2

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

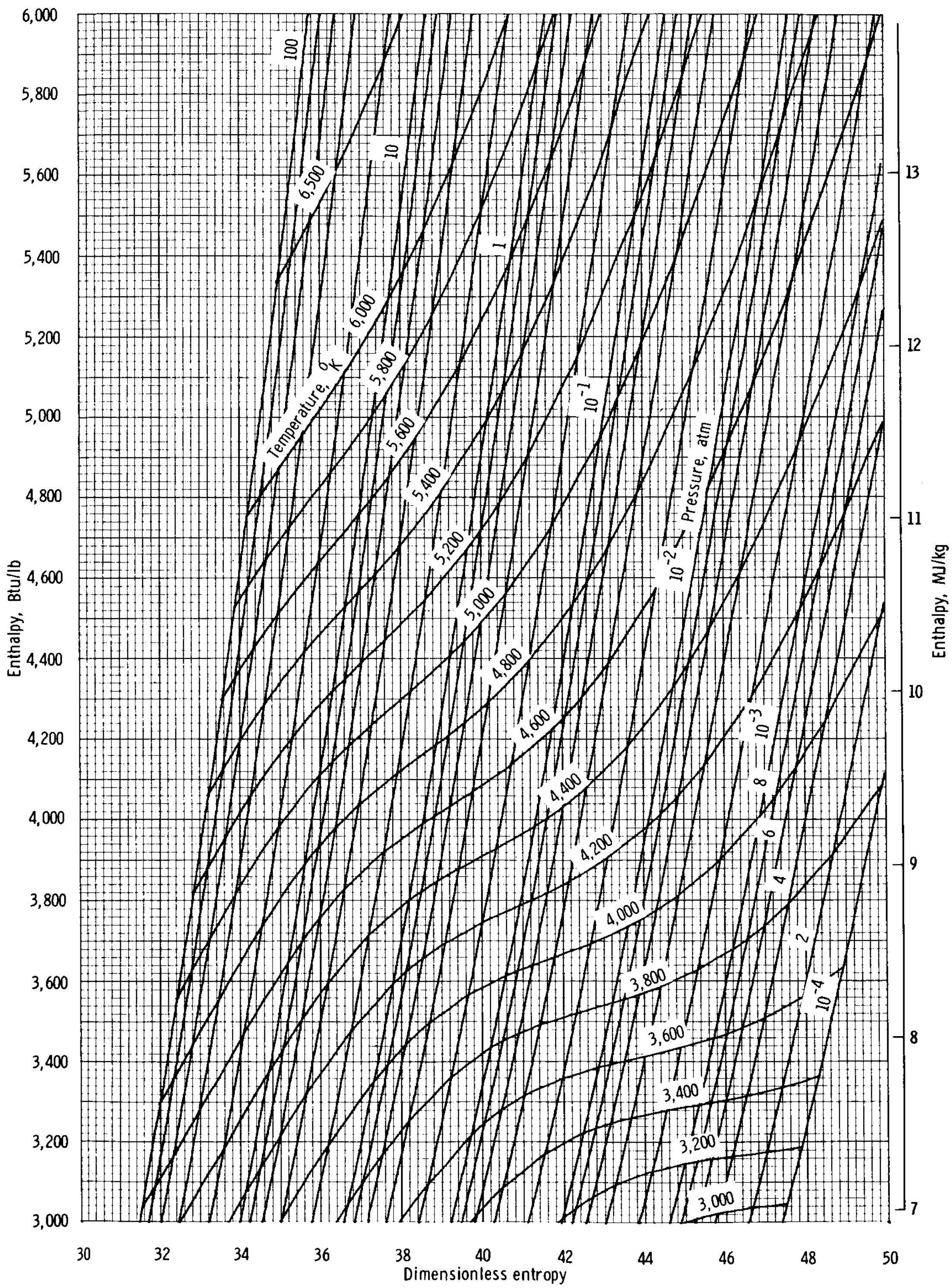


Chart 3

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

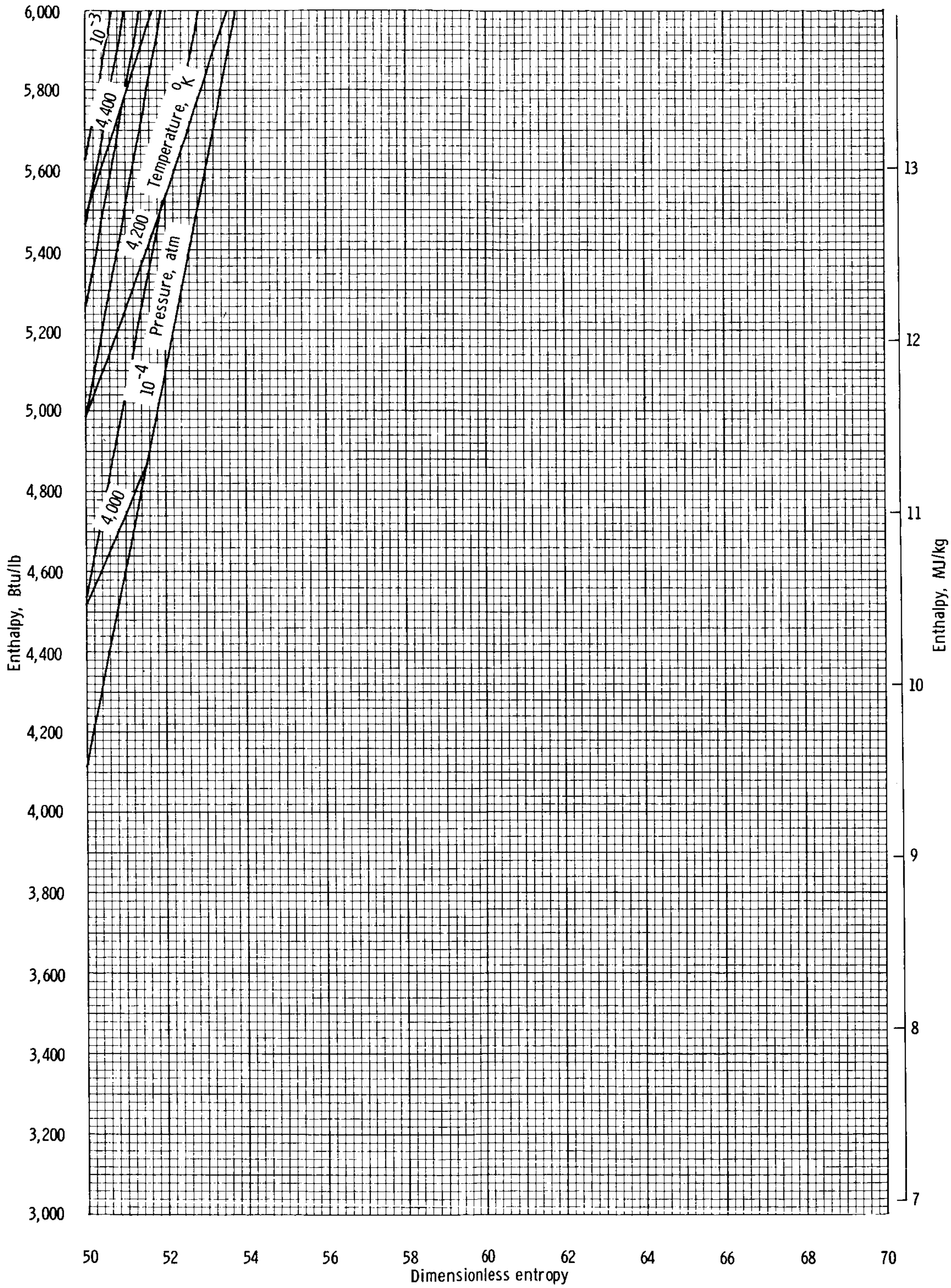


Chart 4

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

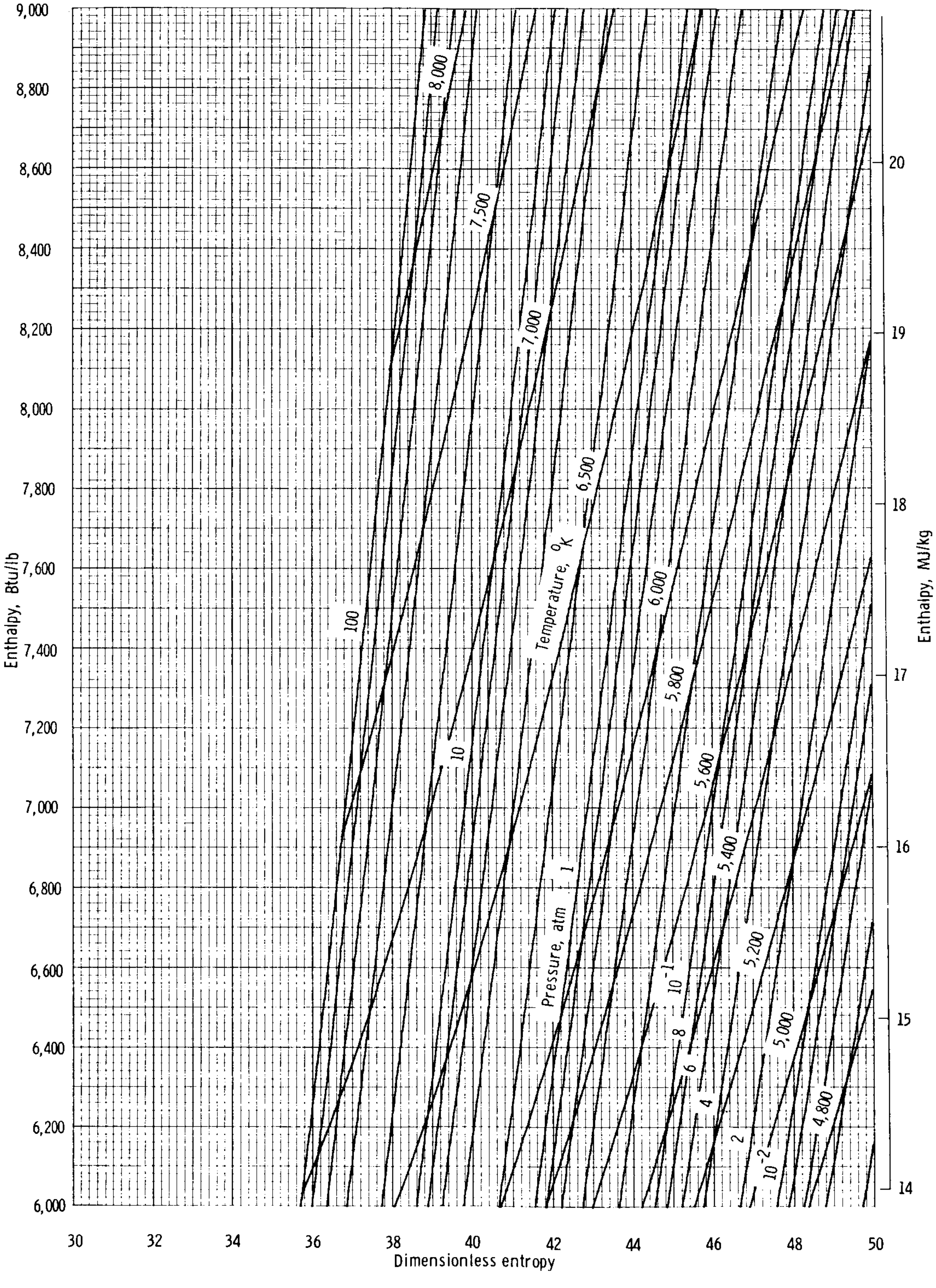


Chart 5

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

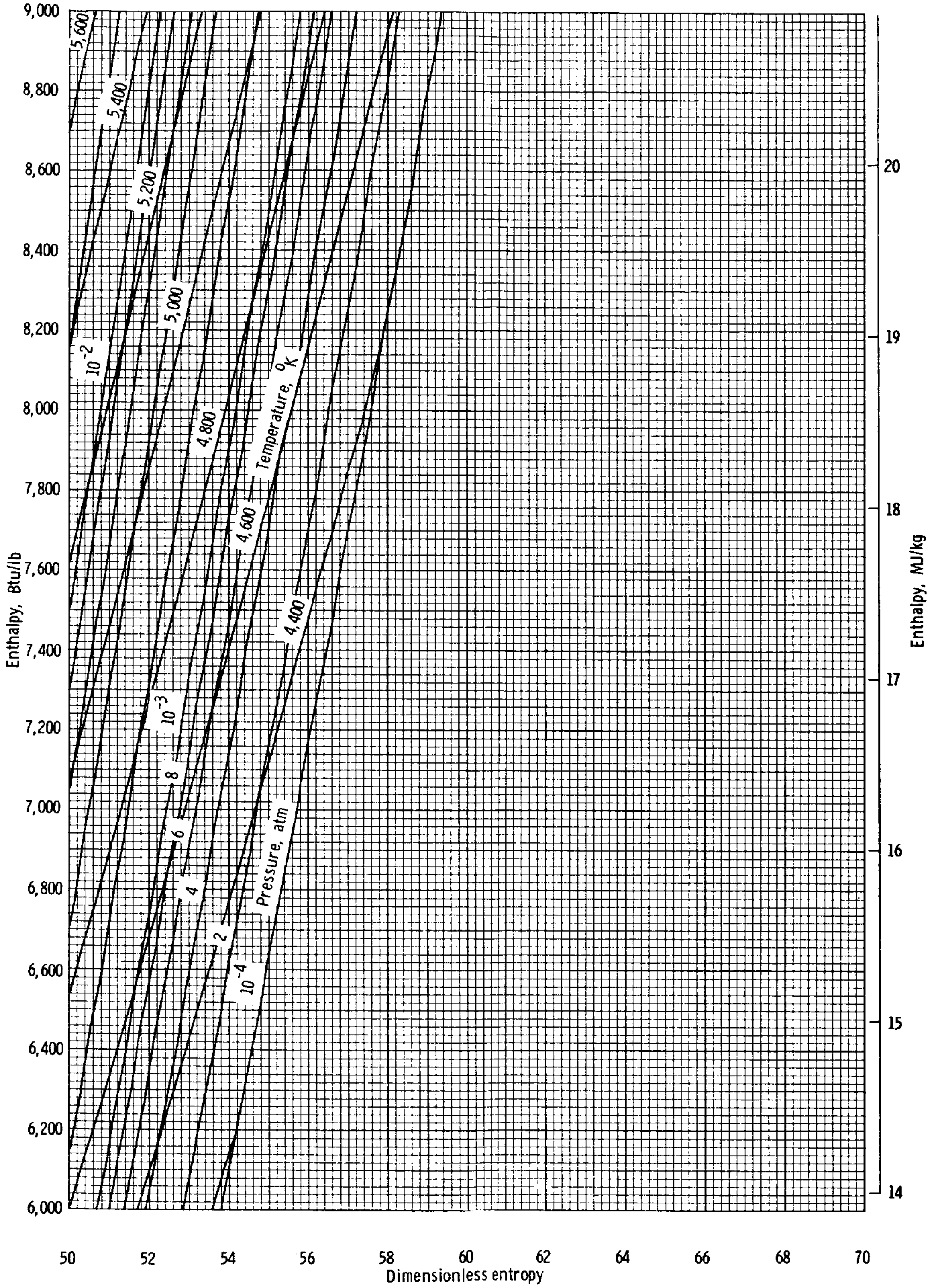


Chart 6

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

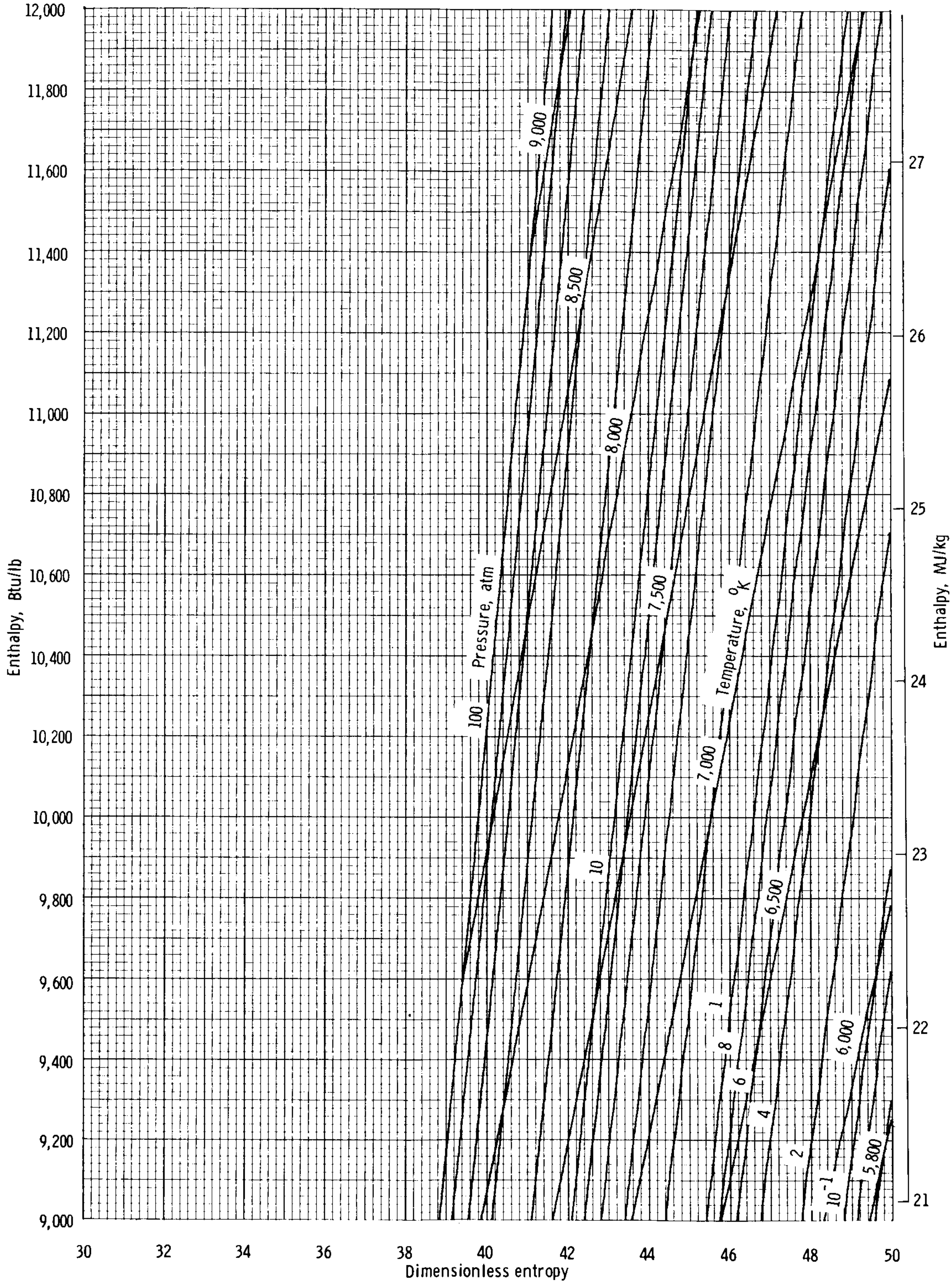


Chart 7

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

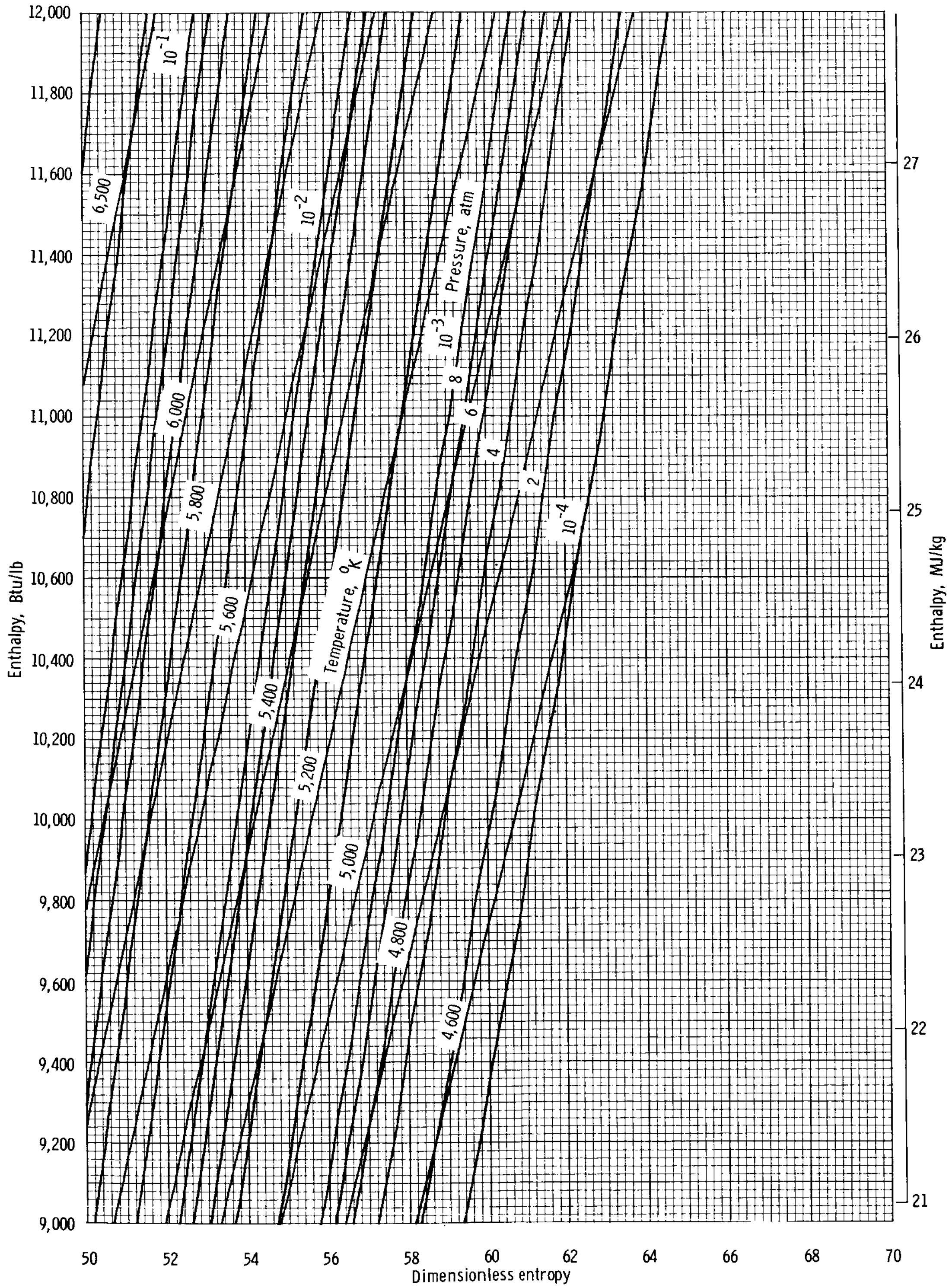


Chart 8

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

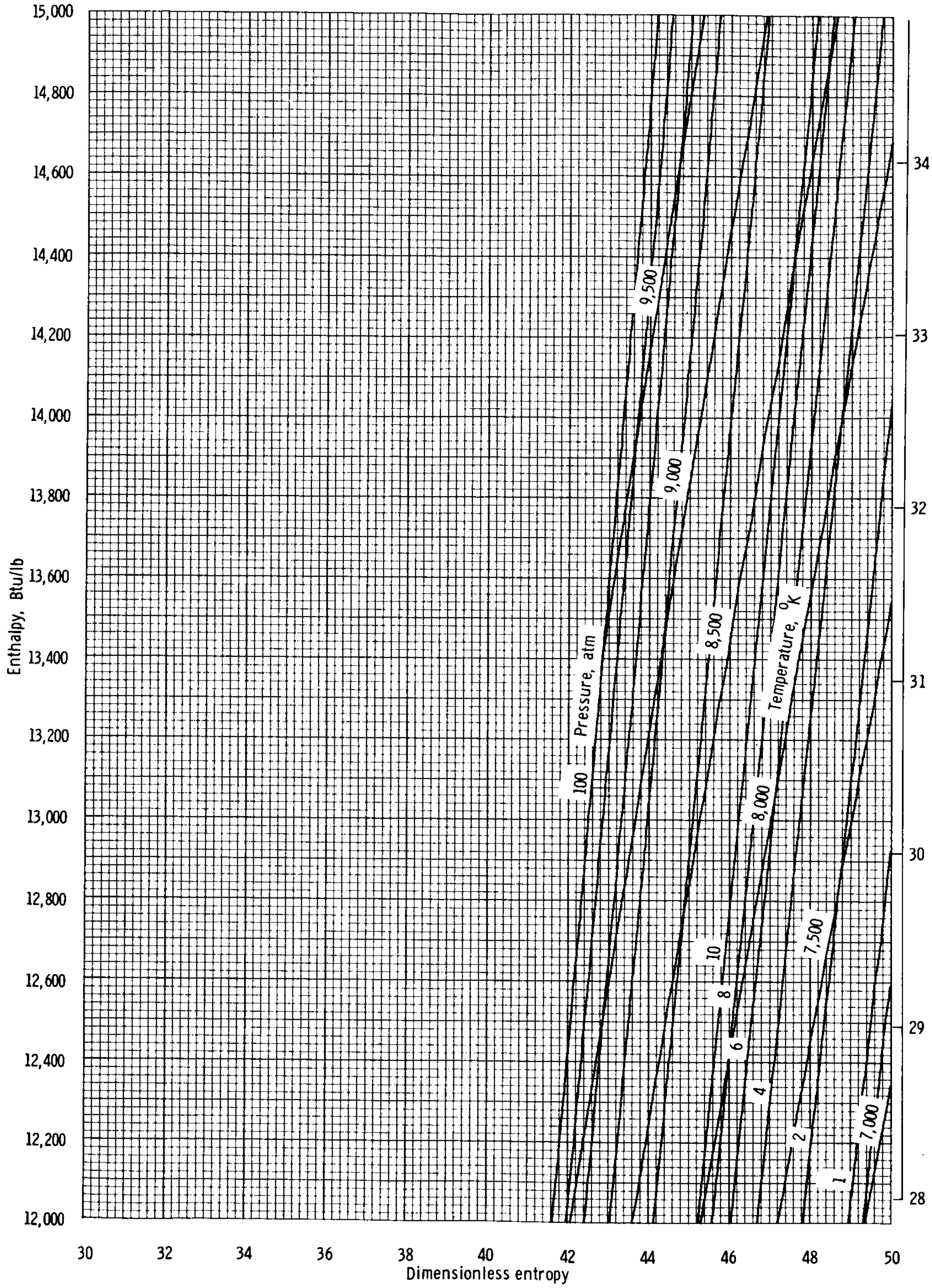


Chart 9

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

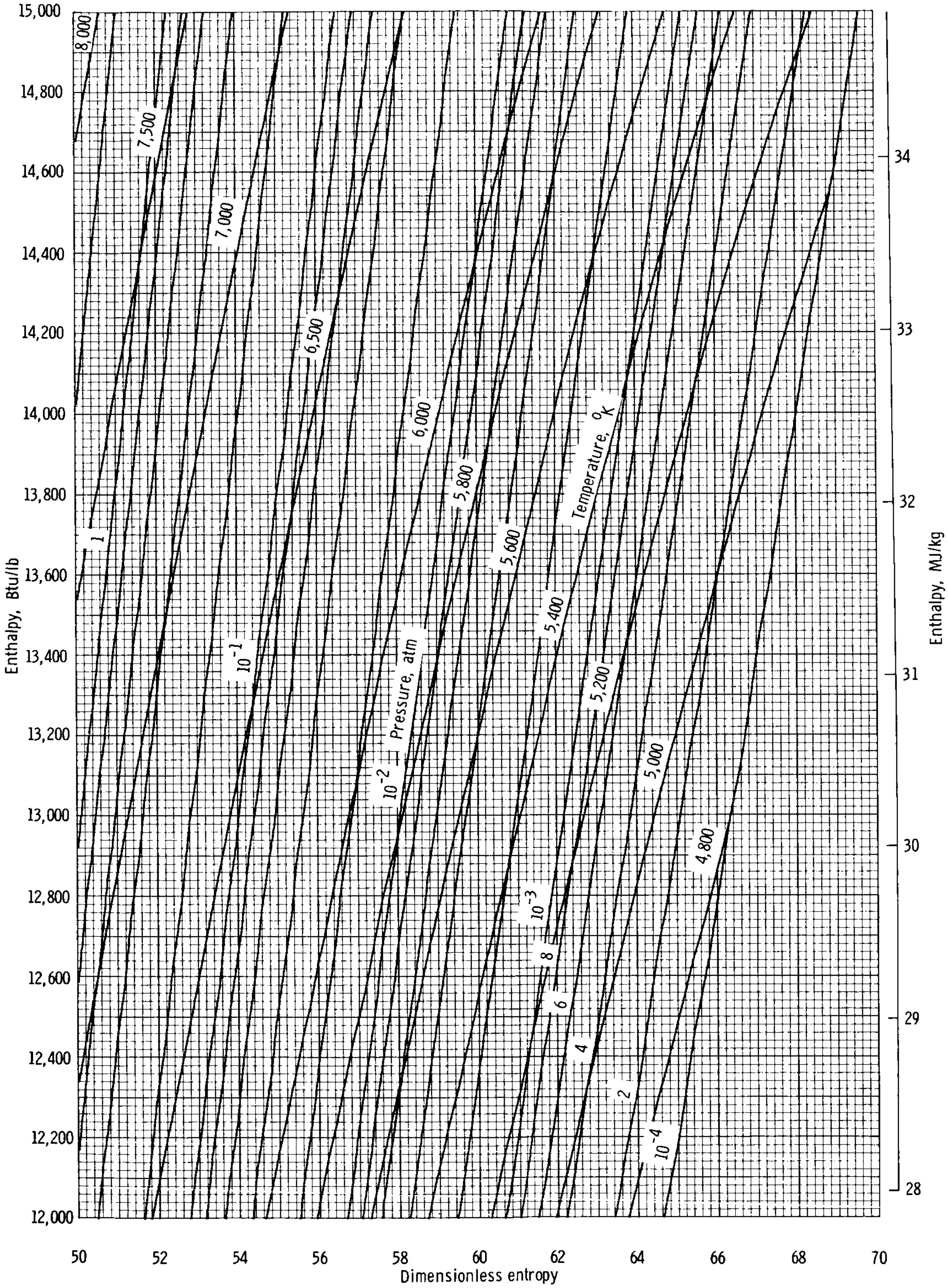


Chart 10

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

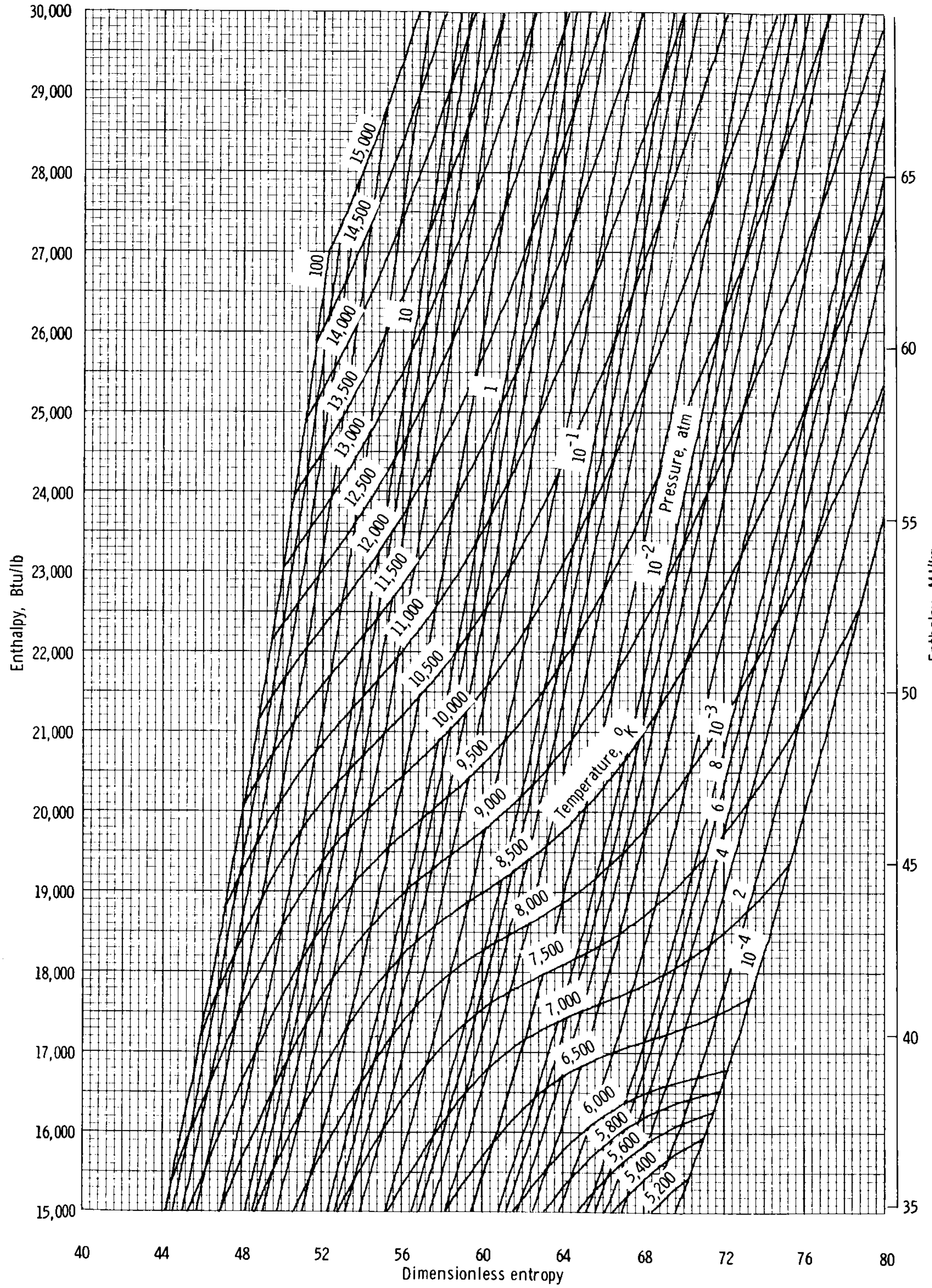


Chart 11

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

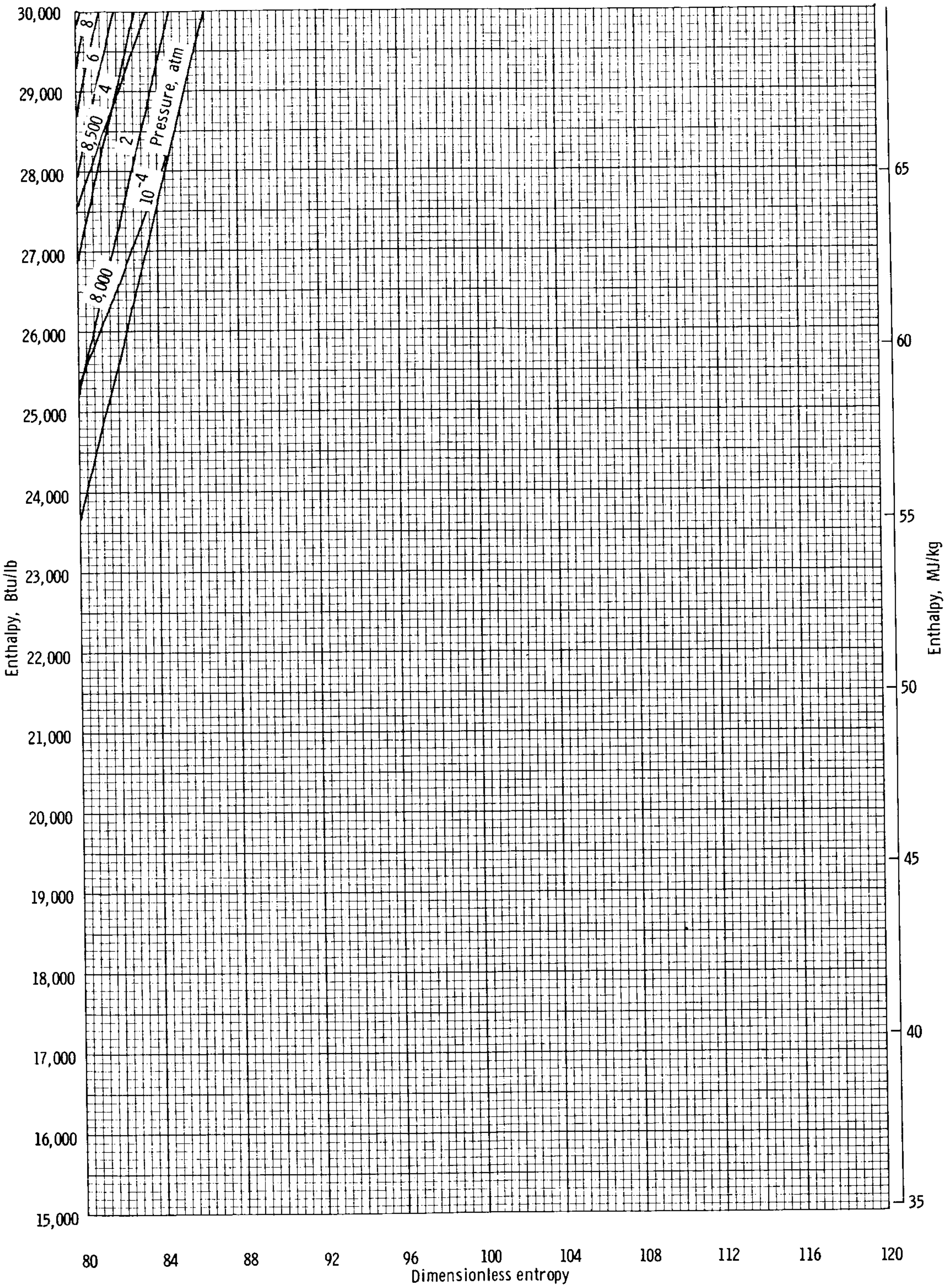


Chart 12

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

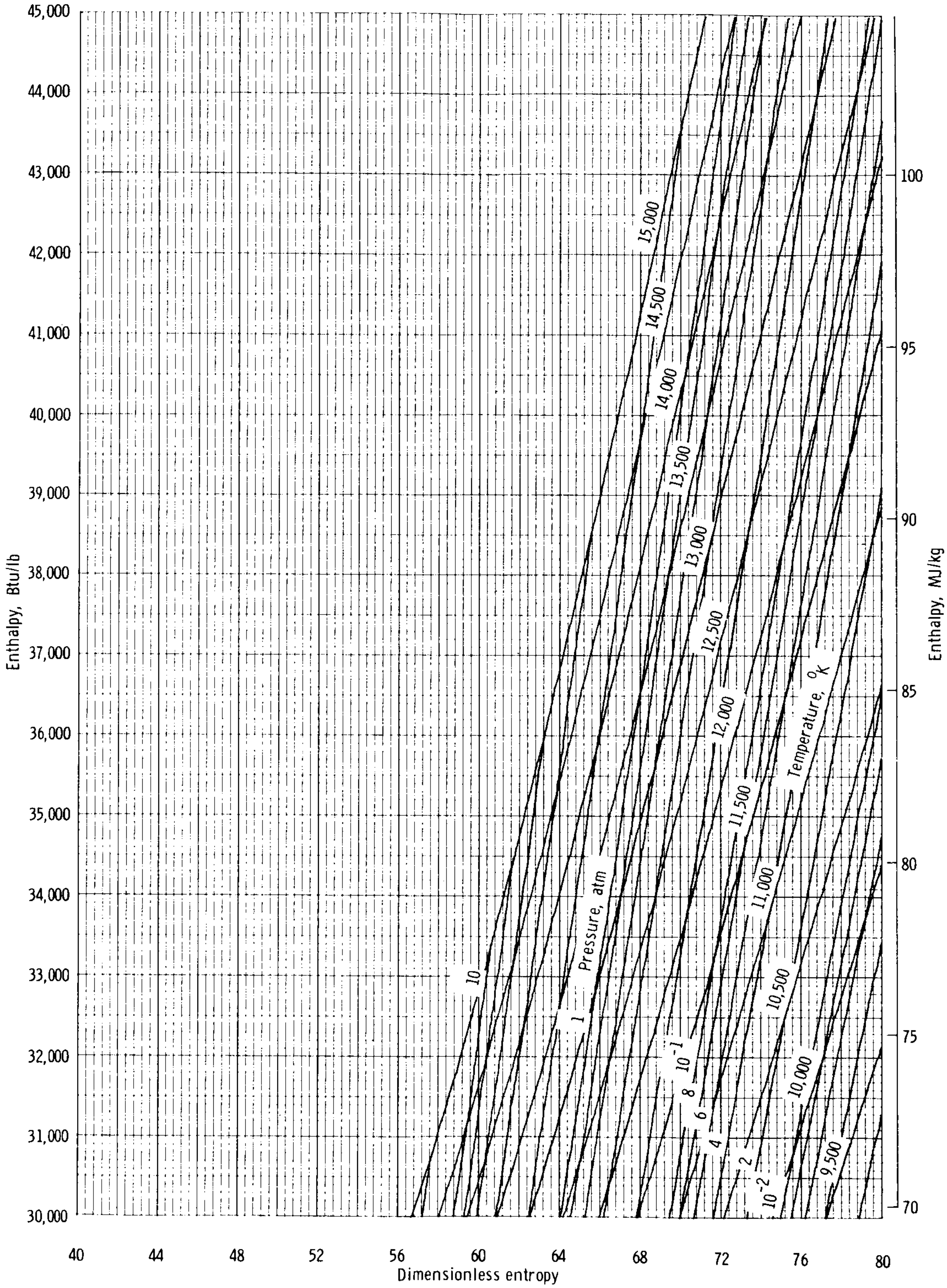


Chart 13

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

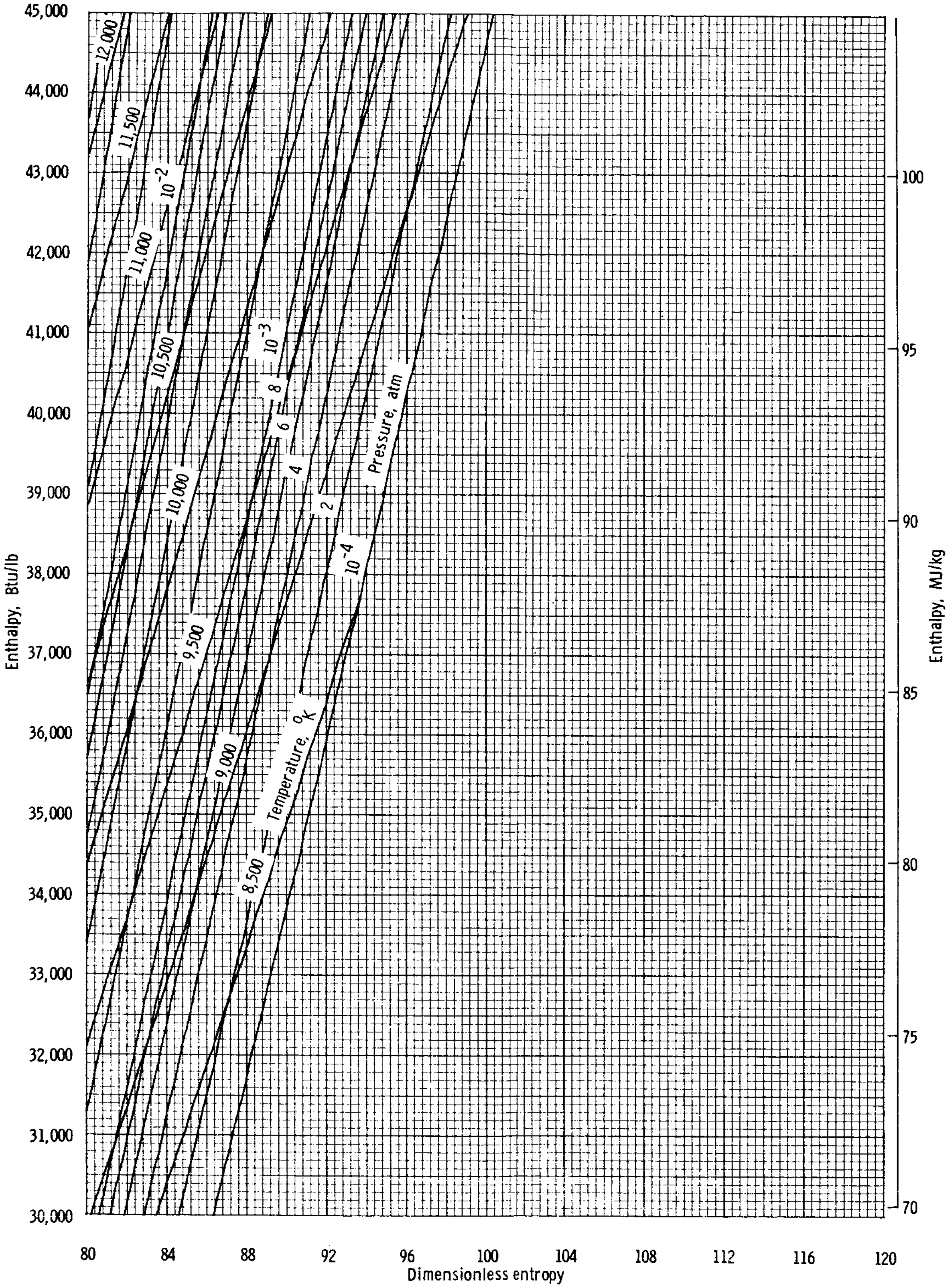


Chart 14

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

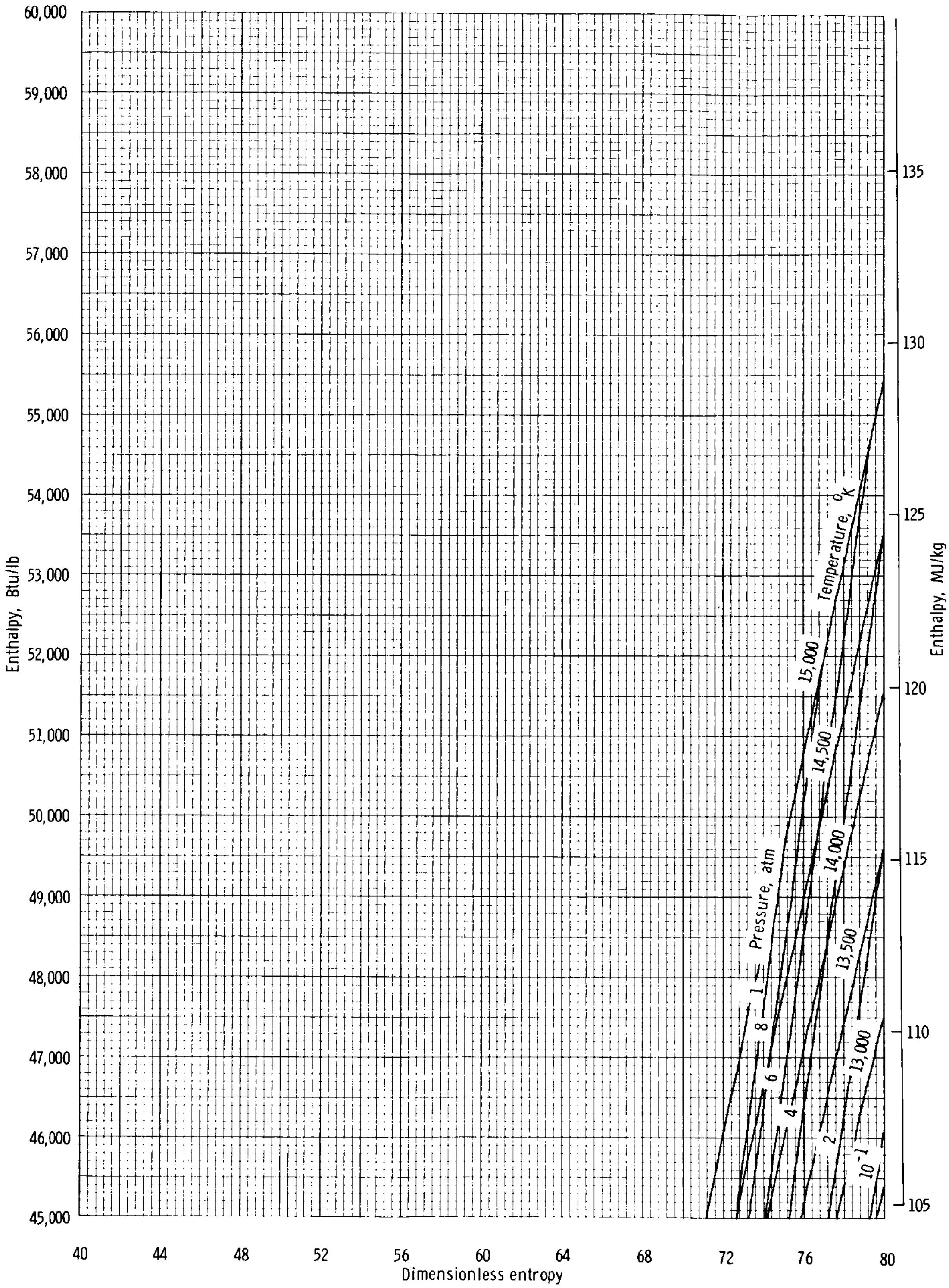


Chart 15

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

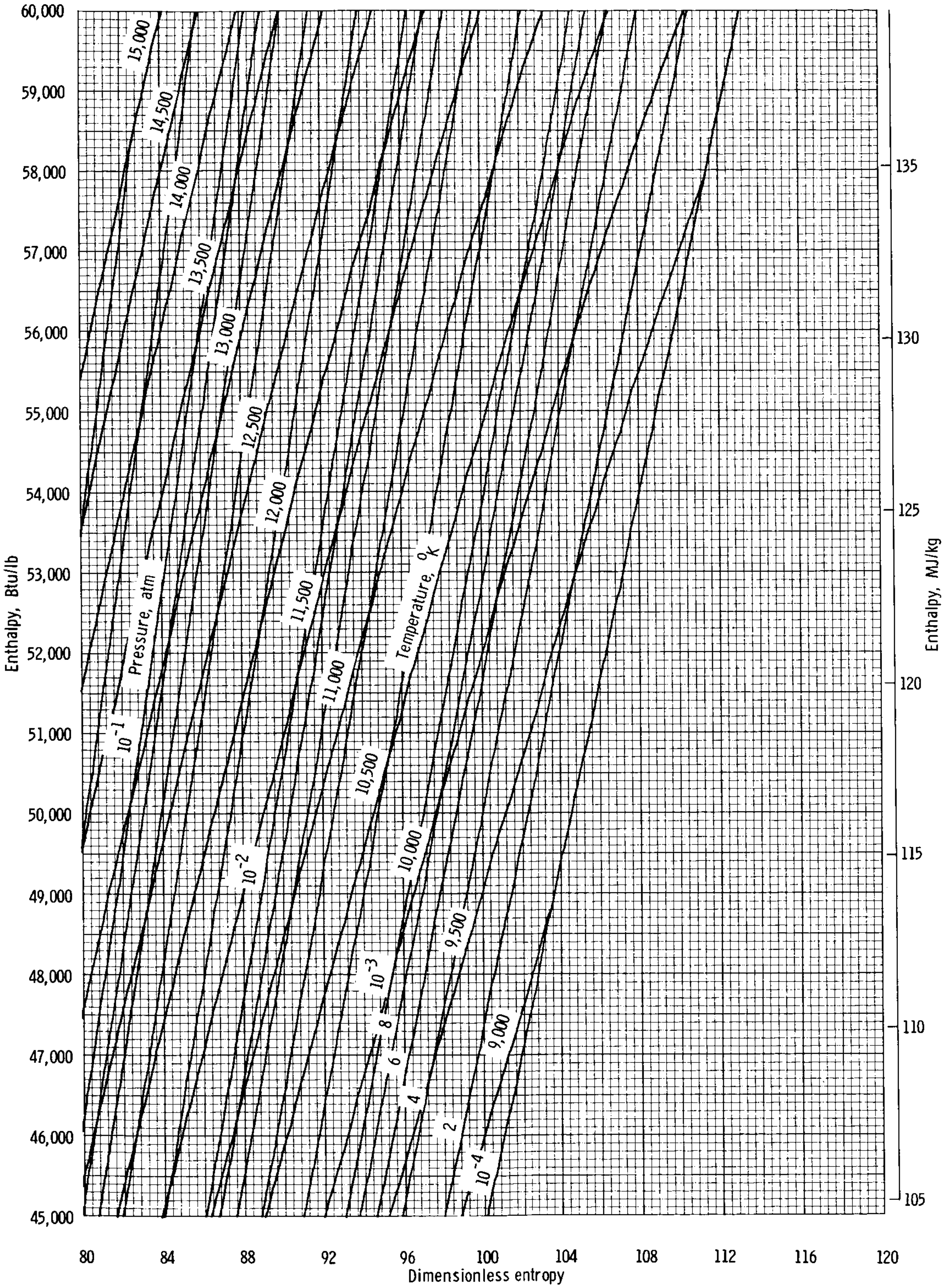


Chart 16

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

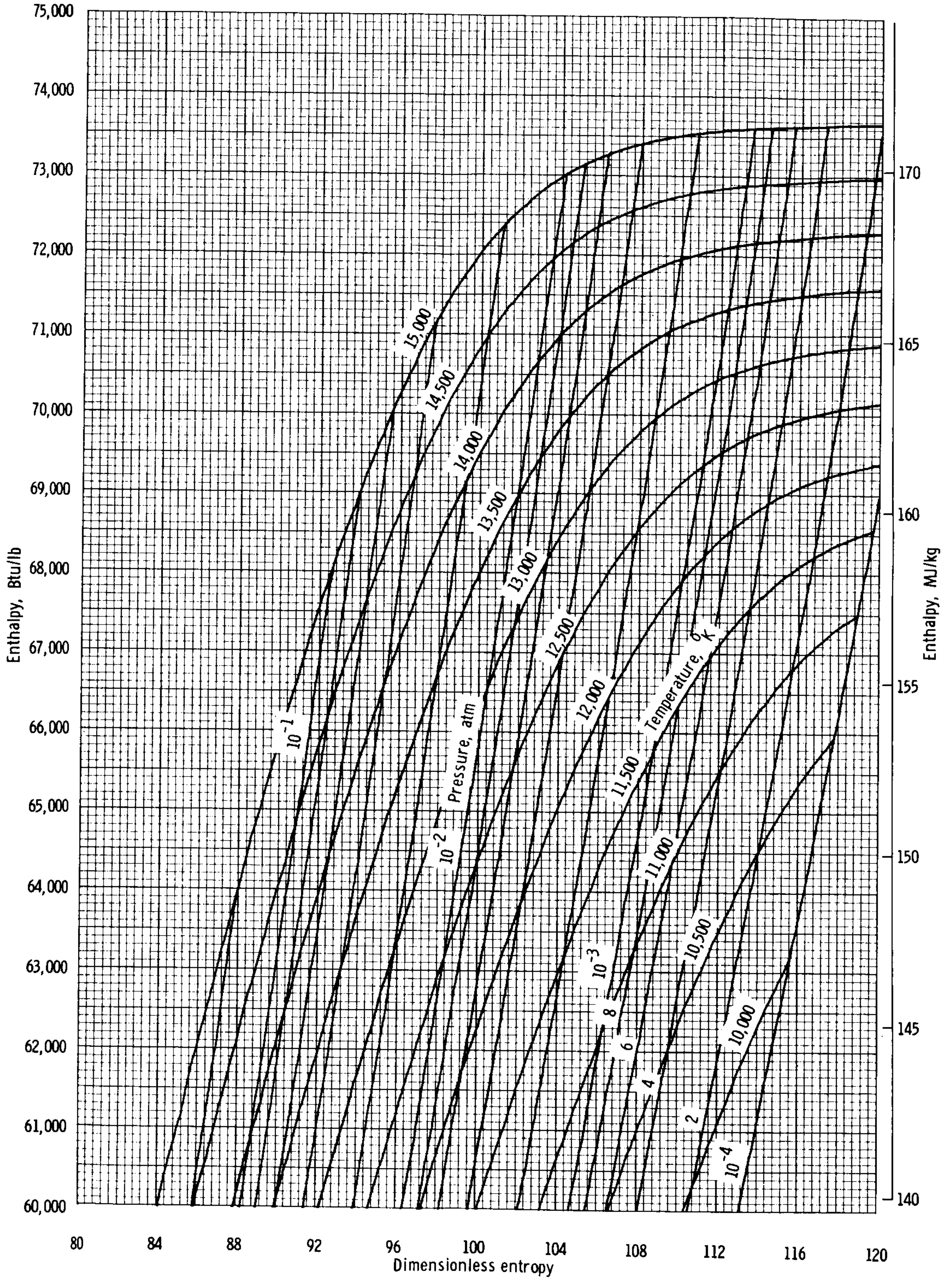


Chart 17

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

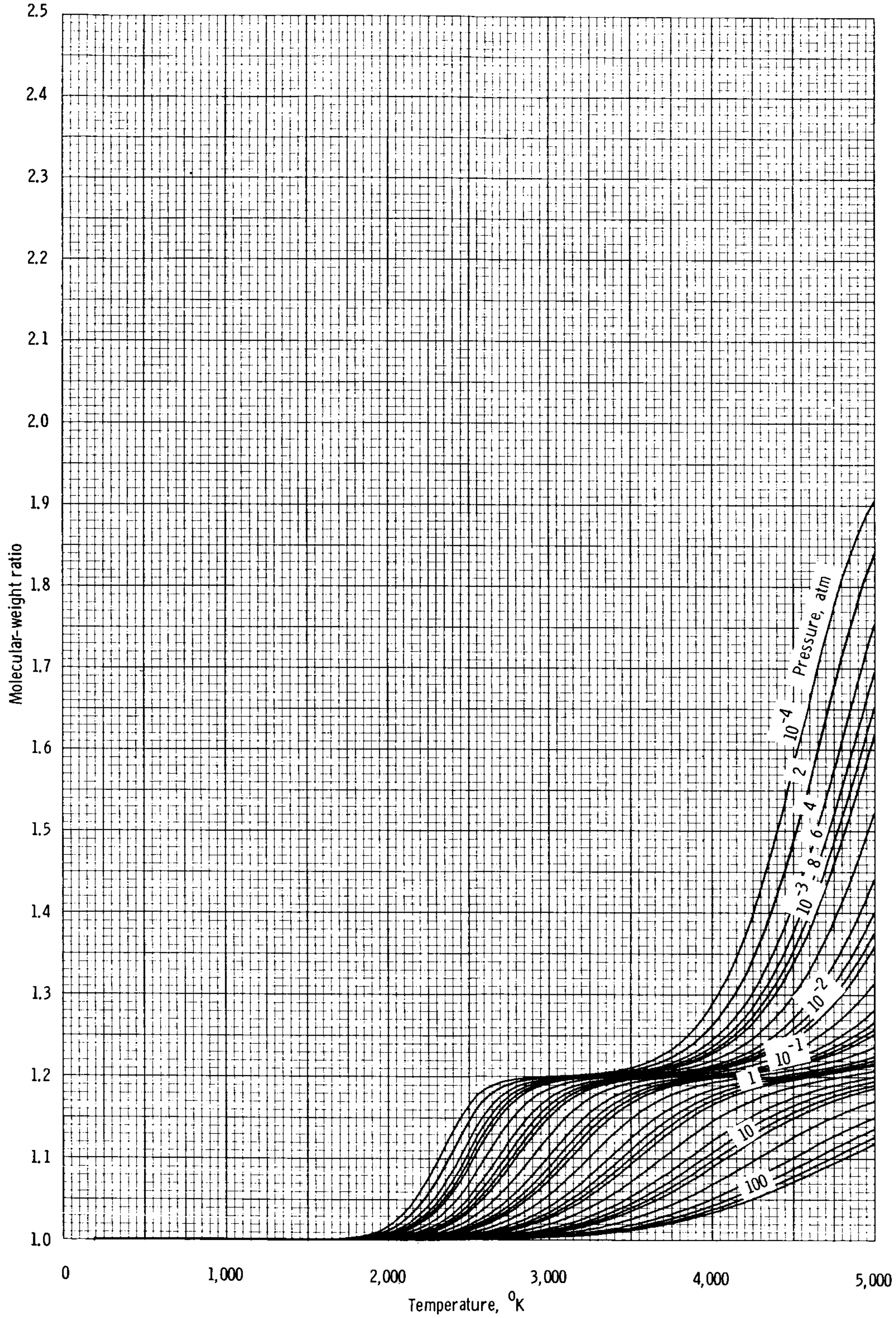


Chart 18

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

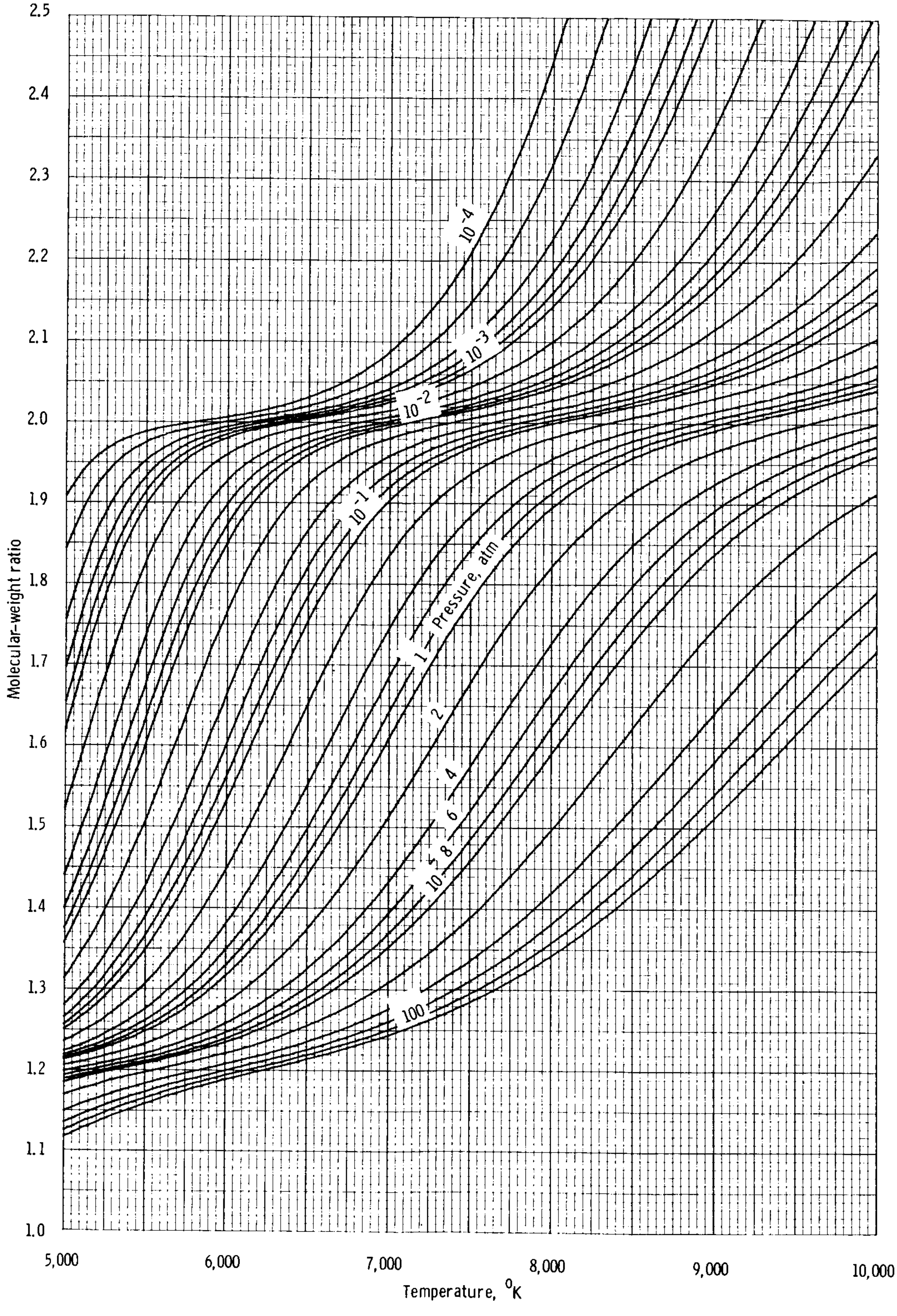


Chart 19

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

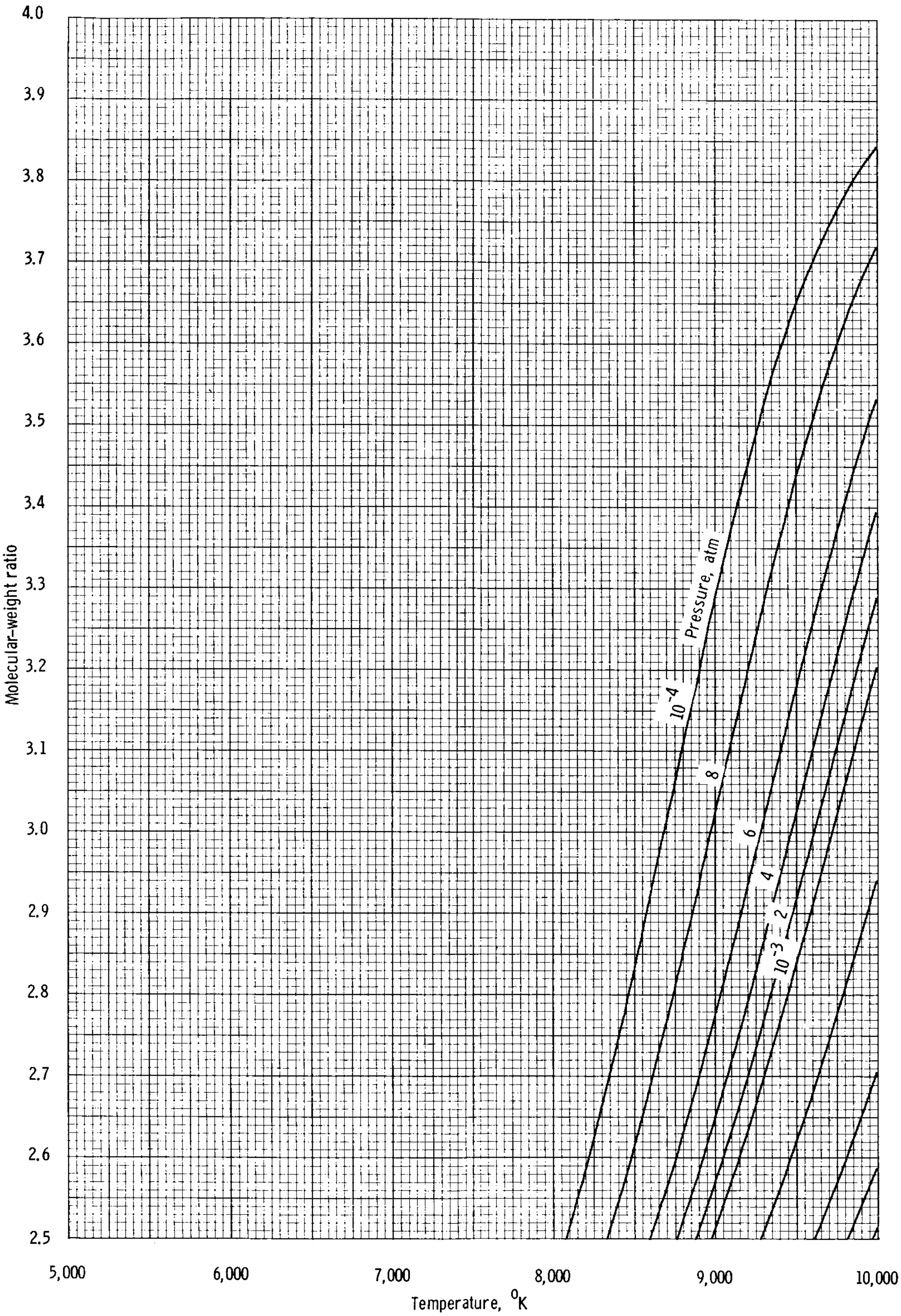


Chart 20

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Continued.

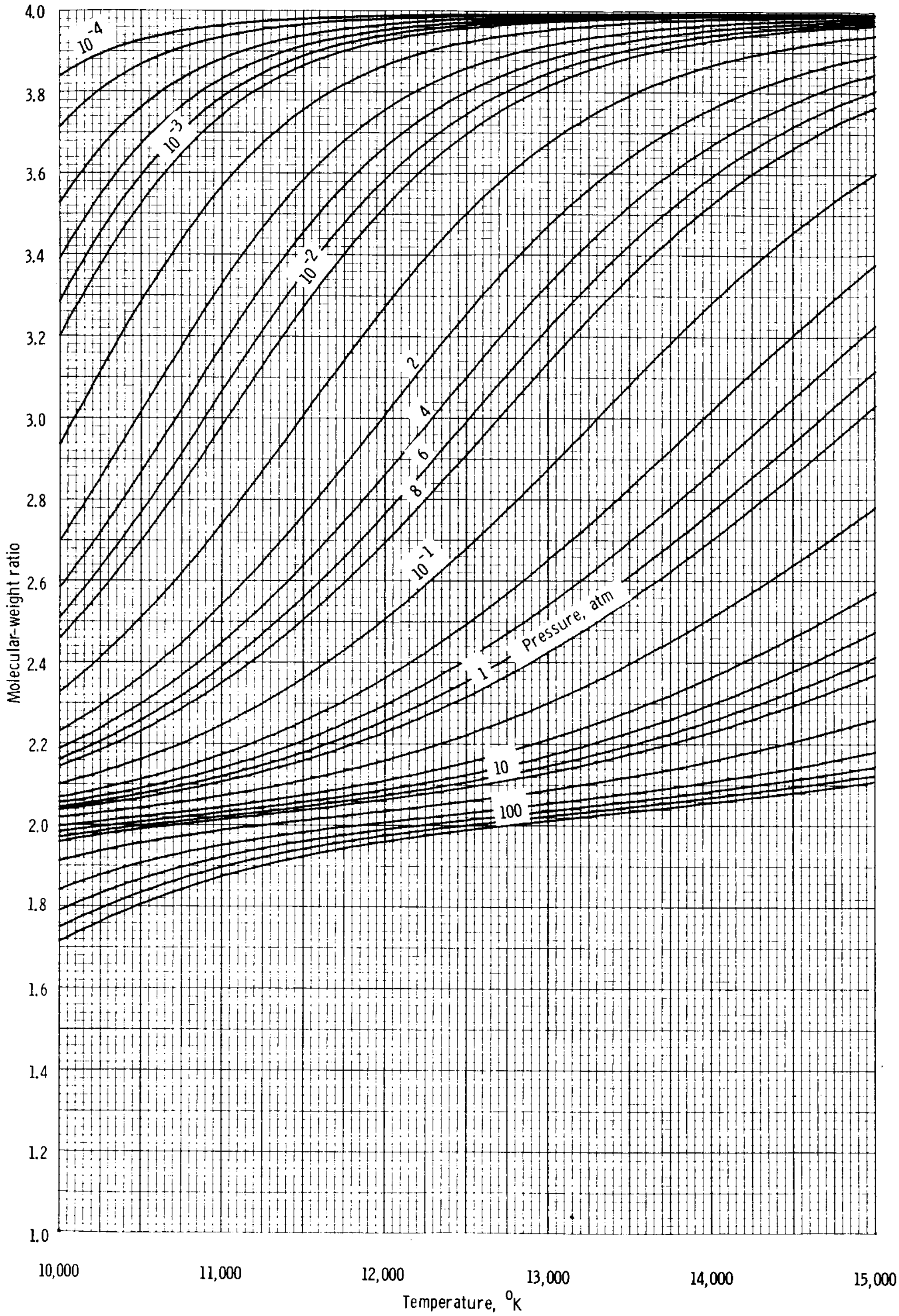


Chart 21

Figure 5.- Thermodynamic charts for 80 percent N_2 and 20 percent O_2. Concluded.

TABLE V.- THERMODYNAMIC PROPERTIES OF 80 PERCENT N_2 AND 20 PERCENT O_2

(a) Ratio of specific heats γ

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3946	1.3946	1.3946	1.3946	1.3946	1.3946	1.3946
600	1.3761	1.3761	1.3761	1.3761	1.3761	1.3761	1.3761
800	1.3546	1.3546	1.3546	1.3546	1.3546	1.3546	1.3546
1,000	1.3373	1.3373	1.3373	1.3373	1.3373	1.3373	1.3373
1,200	1.3248	1.3248	1.3248	1.3248	1.3248	1.3248	1.3248
1,400	1.3159	1.3159	1.3159	1.3158	1.3157	1.3153	1.3141
1,600	1.3093	1.3093	1.3091	1.3087	1.3074	1.3033	1.2911
1,800	1.3043	1.3040	1.3032	1.3006	1.2929	1.2716	1.2253
2,000	1.3000	1.2989	1.2956	1.2858	1.2599	1.2094	1.1527
2,200	1.2958	1.2926	1.2829	1.2577	1.2095	1.1576	1.1359
2,400	1.2909	1.2831	1.2622	1.2198	1.1702	1.1472	1.1479
2,600	1.2846	1.2695	1.2356	1.1882	1.1595	1.1584	1.1813
2,800	1.2763	1.2523	1.2107	1.1748	1.1682	1.1787	1.2712
3,000	1.2663	1.2346	1.1952	1.1781	1.1813	1.2394	1.3038
3,200	1.2554	1.2202	1.1916	1.1888	1.2107	1.2870	1.2659
3,400	1.2450	1.2120	1.1973	1.2019	1.2563	1.2734	1.2039
3,600	1.2368	1.2107	1.2071	1.2245	1.2731	1.2270	1.1544
3,800	1.2317	1.2151	1.2177	1.2515	1.2508	1.1803	1.1314
4,000	1.2303	1.2228	1.2304	1.2600	1.2131	1.1503	1.1332
4,200	1.2324	1.2314	1.2445	1.2441	1.1796	1.1398	1.1537
4,400	1.2371	1.2393	1.2522	1.2171	1.1588	1.1465	1.1809
4,600	1.2434	1.2462	1.2467	1.1919	1.1517	1.1657	1.1929
4,800	1.2499	1.2510	1.2310	1.1744	1.1569	1.1891	1.1801
5,000	1.2557	1.2516	1.2124	1.1662	1.1717	1.2030	1.1683
5,200	1.2598	1.2465	1.1966	1.1670	1.1915	1.1986	1.1853
5,400	1.2618	1.2365	1.1861	1.1755	1.2089	1.1858	1.2315
5,600	1.2613	1.2247	1.1817	1.1896	1.2161	1.1845	1.2770
5,800	1.2583	1.2138	1.1831	1.2061	1.2113	1.2040	1.2878
6,000	1.2530	1.2056	1.1896	1.2210	1.2019	1.2374	1.2660
6,500	1.2349	1.2009	1.2199	1.2278	1.2170	1.2650	1.1886
7,000	1.2225	1.2166	1.2457	1.2162	1.2577	1.2105	1.1547
7,500	1.2230	1.2428	1.2438	1.2367	1.2371	1.1732	1.1635
8,000	1.2354	1.2637	1.2349	1.2517	1.2012	1.1677	1.2015
8,500	1.2552	1.2673	1.2427	1.2353	1.1831	1.1878	1.2419
9,000	1.2753	1.2595	1.2523	1.2131	1.1849	1.2237	1.2438
9,500	1.2885	1.2554	1.2477	1.2010	1.2033	1.2564	1.2154
10,000	1.2913	1.2588	1.2354	1.2015	1.2326	1.2626	1.2114
10,500	1.2869	1.2623	1.2254	1.2131	1.2629	1.2439	1.2567
11,000	1.2819	1.2608	1.2219	1.2335	1.2812	1.2299	1.3404
11,500	1.2802	1.2559	1.2256	1.2588	1.2801	1.2437	1.4281
12,000	1.2816	1.2513	1.2359	1.2834	1.2666	1.2888	1.4919
12,500	1.2835	1.2494	1.2516	1.3009	1.2570	1.3539	1.5291
13,000	1.2843	1.2513	1.2710	1.3072	1.2633	1.4203	1.5485
13,500	1.2840	1.2569	1.2918	1.3030	1.2889	1.4736	1.5582
14,000	1.2836	1.2662	1.3113	1.2947	1.3301	1.5101	1.5630
14,500	1.2840	1.2784	1.3266	1.2897	1.3791	1.5331	1.5655
15,000	1.2858	1.2930	1.3359	1.2933	1.4268	1.5470	1.5669

TABLE V.- THERMODYNAMIC PROPERTIES OF 80 PERCENT N_2 AND 20 PERCENT O_2 - Concluded

(b) Dimensionless speed-of-sound parameter $a^2\rho/p$

T, °K	Pressure, atmospheres, of -						
	100	10	1.0	0.1	0.01	0.001	0.0001
400	1.3946	1.3946	1.3946	1.3946	1.3946	1.3946	1.3946
600	1.3761	1.3761	1.3761	1.3761	1.3761	1.3761	1.3761
800	1.3546	1.3546	1.3546	1.3546	1.3546	1.3546	1.3546
1,000	1.3373	1.3373	1.3373	1.3373	1.3373	1.3373	1.3373
1,200	1.3248	1.3248	1.3248	1.3248	1.3248	1.3248	1.3248
1,400	1.3159	1.3159	1.3159	1.3158	1.3157	1.3153	1.3140
1,600	1.3093	1.3093	1.3091	1.3087	1.3074	1.3032	1.2909
1,800	1.3043	1.3040	1.3032	1.3006	1.2927	1.2710	1.2235
2,000	1.3000	1.2989	1.2955	1.2854	1.2589	1.2064	1.1440
2,200	1.2958	1.2924	1.2825	1.2564	1.2056	1.1468	1.1101
2,400	1.2908	1.2827	1.2609	1.2159	1.1591	1.1210	1.1139
2,600	1.2842	1.2683	1.2322	1.1786	1.1357	1.1230	1.1666
2,800	1.2755	1.2497	1.2032	1.1554	1.1329	1.1570	1.2673
3,000	1.2646	1.2295	1.1811	1.1472	1.1501	1.2315	1.3025
3,200	1.2522	1.2110	1.1685	1.1522	1.1938	1.2841	1.2645
3,400	1.2396	1.1970	1.1651	1.1714	1.2488	1.2715	1.2005
3,600	1.2281	1.1885	1.1700	1.2054	1.2694	1.2239	1.1461
3,800	1.2188	1.1854	1.1832	1.2410	1.2475	1.1740	1.1132
4,000	1.2123	1.1872	1.2039	1.2538	1.2082	1.1374	1.0971
4,200	1.2086	1.1935	1.2266	1.2390	1.1709	1.1155	1.0908
4,400	1.2075	1.2035	1.2403	1.2108	1.1434	1.1041	1.0904
4,600	1.2089	1.2158	1.2379	1.1822	1.1257	1.0996	1.0943
4,800	1.2122	1.2270	1.2227	1.1591	1.1156	1.0994	1.1039
5,000	1.2169	1.2332	1.2025	1.1427	1.1108	1.1026	1.1241
5,200	1.2223	1.2316	1.1831	1.1319	1.1096	1.1098	1.1628
5,400	1.2274	1.2232	1.1671	1.1257	1.1113	1.1231	1.2202
5,600	1.2309	1.2110	1.1550	1.1227	1.1155	1.1463	1.2707
5,800	1.2318	1.1979	1.1466	1.1222	1.1229	1.1821	1.2834
6,000	1.2297	1.1859	1.1411	1.1237	1.1349	1.2247	1.2617
6,500	1.2140	1.1648	1.1368	1.1363	1.1931	1.2592	1.1791
7,000	1.1954	1.1554	1.1420	1.1669	1.2482	1.2017	1.1309
7,500	1.1823	1.1542	1.1558	1.2152	1.2288	1.1545	1.1113
8,000	1.1754	1.1589	1.1809	1.2400	1.1874	1.1299	1.1057
8,500	1.1737	1.1689	1.2135	1.2240	1.1579	1.1196	1.1076
9,000	1.1758	1.1847	1.2349	1.1968	1.1413	1.1174	1.1155
9,500	1.1812	1.2057	1.2333	1.1750	1.1336	1.1202	1.1330
10,000	1.1898	1.2267	1.2187	1.1609	1.1317	1.1276	1.1695
10,500	1.2014	1.2396	1.2025	1.1531	1.1337	1.1412	1.2366
11,000	1.2158	1.2413	1.1895	1.1498	1.1389	1.1656	1.3305
11,500	1.2311	1.2354	1.1805	1.1499	1.1477	1.2068	1.4230
12,000	1.2447	1.2267	1.1751	1.1525	1.1614	1.2678	1.4892
12,500	1.2539	1.2183	1.1725	1.1573	1.1825	1.3418	1.5276
13,000	1.2581	1.2114	1.1722	1.1645	1.2137	1.4132	1.5477
13,500	1.2580	1.2063	1.1738	1.1745	1.2565	1.4693	1.5577
14,000	1.2555	1.2031	1.1769	1.1883	1.3090	1.5075	1.5628
14,500	1.2518	1.2015	1.1815	1.2068	1.3651	1.5315	1.5654
15,000	1.2481	1.2013	1.1876	1.2312	1.4175	1.5460	1.5668

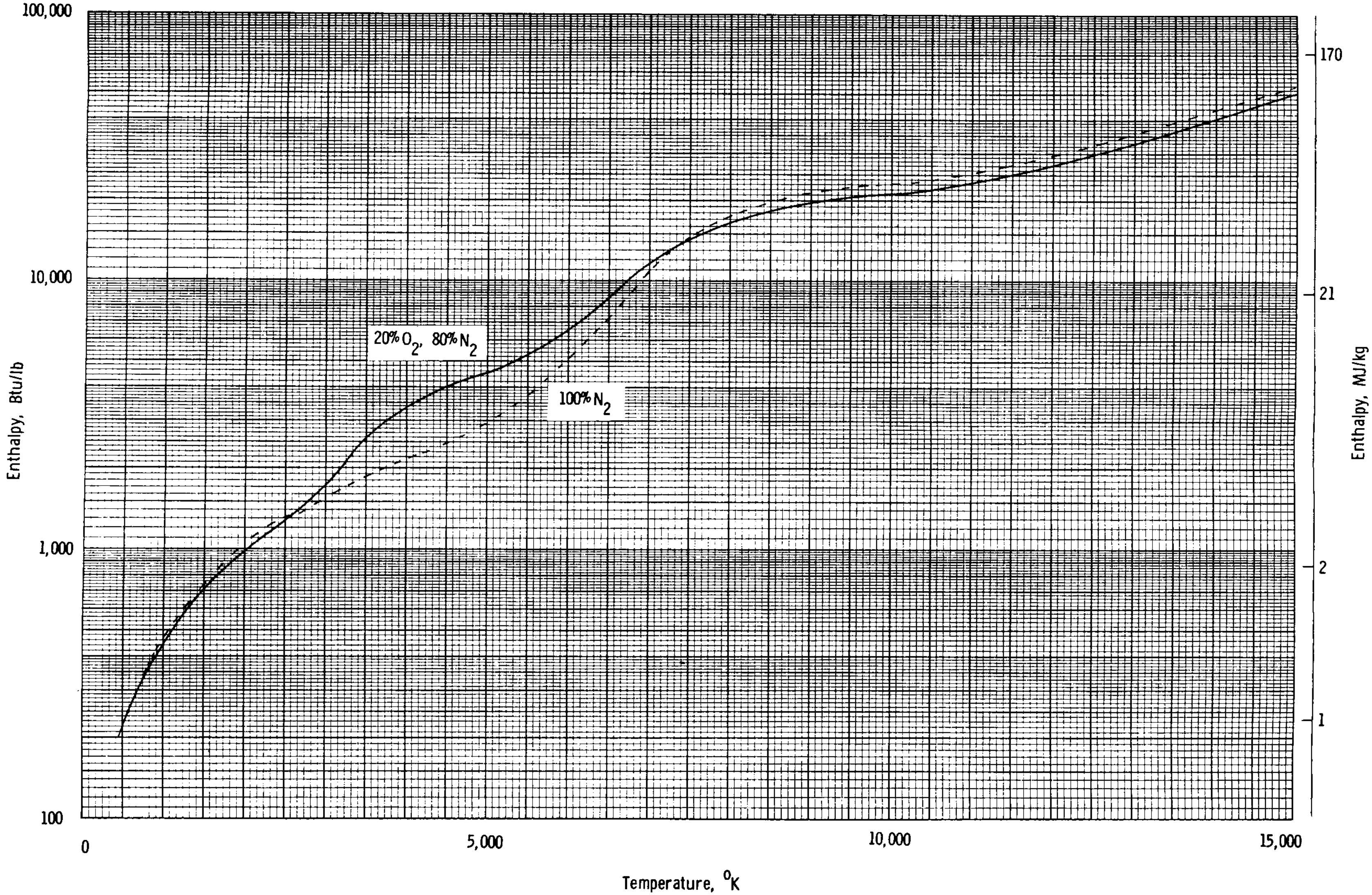


Figure 6.- Comparison of enthalpy as a function of temperature for air and nitrogen at 1 atmosphere.

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